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Tests of Reinforced Concrete T-Beams

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TESTS OF REINFORCED CONCRETE T-BEAMS

BY

RUBEY OSGOOD HARDER
CHARLES EUGENE WATERHOUSE

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

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June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES EUGENE WATERHOUSE
RUBEY OSGOOD HARDER

ENTITLED TESTS OF REINFORCED-CONCRETE T-BEAMS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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TESTS OF REINFORCED CONCRETE T-BEAMS.

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TESTS ON REINFORCED CONCRETE T-BEAMS

I. INTRODUCTION.

a. Object of Tests.- When a reinforced concrete floor and its supporting beams are built as one piece, the resulting composite structure forms a system of T-shaped beams. T-shapes may also be used in the design of bridge girders and other structures for special conditions. The large amount of reinforcement which may be put into a T-beam without encroaching on the compressive strength of the concrete too far and the resulting high web stresses developed in the stem of the T-beam make the T-beam an advantageous form of test piece for determining the efficiency of various forms and amounts of web reinforcement. This feature of T-beam testing is, in itself, sufficient reason for the conducting of tests on T-beams. The object of this series of tests on reinforced concrete T-beams was to determine the effect on the strength of the beam of different web reinforcements as to amount, quality and form, and to determine the position of the neutral axis. The determination of the position of the neutral axis enables one to make an economic and efficient design of a T-shaped beam wherever used.

During these tests Mr. D. A. Abrams carried on a set of tests on the same T-beams to determine if there was any difference in the compressive stresses across the width of the flange. No results were obtained, either because there was no

difference in the compressive stress across the flange or the apparatus used was not delicate enough to register any differences.

b. Scope of Test.- These tests were made in the Laboratory of Applied Mechanics at the University of Illinois under the immediate supervision of D. A. Abrams, Associate in the Engineering Experiment Station. Fifteen beams were tested in all. The beams were of uniform mixture of concrete and of uniform size: the flanges were 32 in. wide, 3 in. thick; webs were 8 in. thick and 9 in. in depth; and the length was 11 ft. The longitudinal reinforcements consisted of 6 3/4-in. corrugated steel bars laid horizontally. The webs were reinforced with U-shaped vertical stirrups, in some of the beams the stirrups were 1/4-in. mild steel corrugated bars spaced 3 in. apart and in others 1/2-in. plain round rods, 1/2-in. high-steel corrugated bars, and 5/8-in. plain round rods, spaced 6 in. apart. No stirrups were used in T-beams No. 85, 86, and 87.

In all the beams but three, No. 55, 56, and 85, 6 1/2-in. corrugated bars were placed across the flange, these being placed in the region of each load point and spaced 6 in. apart.

Tests on T-beams along the same lines as these were made here in 1907 by Raymond C. Yant, Frank L. Bodwell, and Merle J. Trees.

In 1906 tests were made on T-beams using three top widths of beams equal respectively to two, three, and four times the width of the stem of the beam. One size and spacing

of stirrups were used. These tests were carried on by F. S. Hewes and C. A. Hewes of the class of '06. Similar tests were made at the University of Wisconsin in 1906.

II. THEORY AND AVAILABLE DATA

It is assumed that the concrete and steel adhere perfectly and therefore deform equally and also that a plain section before bending remains a plain section after bending.

It is also assumed that the materials of the beam obey Hooke's law which is briefly stated: Stress is proportional to strain.

The purpose of steel reinforcement is to carry the principal tensile stresses; the concrete being depended upon for the compressive and shearing stresses.

From the first assumption comes--The unit deformations of the fibers at any section of a beam are proportional to their distances from the neutral surface. From the second assumption comes--The unit stresses in the fibers at any section of a beam also are proportional to the distances of the fibers from the neutral surface.

The deformation in the upper fibers and the steel were computed upon the first assumption and what follows from it that the deformation in any fiber is directly proportional to its distance from the neutral surface.

Available Data.- Tests of a similar character were carried on at the University of Illinois Testing Laboratory and the results of these tests are given in Bulletin No. 12 of the University of Illinois Engineering Experiment Station. The average maximum load taken by these T-beams was about 80 000 lb. and at the first diagonal crack was 36 000 lb. The load which will produce failure by tension in the concrete is 17 000 lb., no matter how wide the flange. The horizontal shear was about 600 lb. per sq. in.

III. MATERIALS, TEST PIECES, AND METHODS OF TESTING.

(a) Materials.- In order to conform as near as possible to actual practice all the materials were obtained in the open market.

The stone used in this concrete was a good quality of rather hard limestone from Kankakee, Illinois, ordered screened through a 1-in. and over a 1/4-in. screen. It contained 50% voids and weighed 80.3 lb. per cu. ft. In the determination of the voids in the sand and stone the material was poured slowly into a vessel containing water so that the voids became filled with water and no air was caught.

The sand was of good quality from near the Wabash river at Attica, Indiana. It was fairly clean, sharp, and well graded; contained 28% voids and weighed 106.3 lb. per cu. ft. Table 1 gives results of a mechanical analysis of this sand. The results given are an average of several trials from samples taken at different times throughout the season.

Table 1.

Mechanical Analysis of Sand.

Sieve No.	Separation size inches	Per cent passing
3		99.2
5		89.0
10	0.073	64.7
12		57.8
16	0.042	49.9
18	0.037	39.0
30	0.022	21.6
40	0.015	11.8
50	0.011	5.1
74	0.0078	2.6
150	0.00325	0.46

The concrete was made of the proportions of 1 of cement, 2 of sand, and 4 of stone, measured by loose volume and then weighed as a check on the proportions. The sand and cement were first mixed dry and then the stone, which had previously been wetted, was added. Water was then added and the whole mass mixed by hand with shovels until uniform in appearance. The mass was so wet that water flushed to the surface when tamped.

The steel used for longitudinal reinforcement in each of the beams consisted of 6 3/4-in. Johnson high-steel corrugated bars laid horizontally in two planes, 4 bars in the lower plane 10 5/16 in. below the top and two bars in the upper plane 9 5/16 in. below the top. The elastic limit of the steel ranged from 53 000 lb. to 63 000 lb. per sq. in. The stirrups used were 1/4-in. mild steel corrugated bars, 1/4-in. and 1/2-in. high-steel corrugated bars, and 1/2-in. and 5/8-in. mild-steel round rods. The position and spacing of the longitudinal bars and the distribution and spacing of stirrups is shown on page 14.

Table 2.

Tensile Tests of Steel.

Size inches	Elastic Limit pounds.	Ultimate Strength pounds.	Per cent Elongation in 8 inches	Elastic Limit lb. per sq. in.	Ultimate Strength lb. per sq. in.
Longitudinal Steel Corrugated Bars.					
3/4	32 700	50 960	10.5	58 100	90 500
	31 800	53 780	12.5	56 500	95 800
	35 000	57 930	7.5	62 200	103 000
	30 000	49 140	11.0	53 400	87 500
	29 000	48 470	18.5	51 600	92 000
	32 000	53 690	8.0	56 900	95 500
	36 000	55 400	6.5	64 000	98 500
	32 000	56 250	11.5	57 000	100 000
	34 500	52 900	6.0	61 400	94 000
	34 500	55 150	8.0	61 400	98 300
	35 500	52 180	9.0	63 100	93 000
	40 000	54 940	7.0	71 200	97 800
	36 000	64 690	7.0	64 100	115 000
	33 000	54 880	4.0	58 700	97 600
	29 000	48 470	5.5	51 600	86 200
	34 000	53 600	6.5	60 500	95 500
	26 500	42 700	14.0	47 200	76 000
	33 000	54 910	15.0	58 700	97 800
Stirrups Corrugated Bars.					
1/4	5 340	6 500	10.0	85 400	104 000
	5 340	6 530	10.0	84 200	104 500
	2 480	3 640	18.0	39 700	58 300
	2 500	3 600	15.5	40 000	57 600
Stirrups Plain Round Rods.					
1/2	8 200	12 100	30.	40 100	59 300
	8 400	12 600	29	41 100	62 200
	8 400	12 600	28	41 100	62 200
	8 400	12 700	29	41 800	63 000
	8 500	12 500	29	41 500	61 700
Stirrups Corrugated Bars.					
1/4	2 200	3 300	24	35 200	52 800
	2 300	3 100	28	36 800	49 600
	2 200	3 200	25	35 200	51 200
	2 300	3 200	28	36 800	51 200
	2 200	3 300	27	35 200	52 800

Table 2 continued.

1/2	12 400	20 600	18	49 600	82 400
	12 600	21 100	18	50 400	84 400
	11 800	19 200	19	47 200	76 800
	12 600	20 700	21	50 400	82 800
	12 400	20 500	18	49 600	82 000
	12 500	21 000	20	50 000	84 000
	12 800	21 100	20	51 210	84 400
	12 400	20 700	15	49 600	82 800
	11 800	19 300	22	47 200	77 700
	14 200	24 000	14	56 800	96 000
			Average	50 200	83 200

(b) Test Specimens.- Table 3 gives data on specimens which were made and tested. The 15 T-beams included in this report were similar in every respect except in the disposition of the reinforcement. They were each 11 ft. long and the distance between the supports in the test was 10 ft. The thickness of the flange was 3 in., the width of flange 32 in., width of web 8 in., depth from top of flange to bottom of web 12 in., depth from top fiber to center of steel 10 in. The proportion of longitudinal reinforcement was 1.05%, based on area of enclosing rectangle as shown in Fig. 1, which was obtained by dividing the area of the steel by the product obtained by multiplying the width of flange by effective depth. The reinforcing was arranged symmetrically with respect to the axis of the beam. They were placed in two planes, 4 rods in the lower plane 10 5/16 in. below the top and 2 rods in the upper plane 9 5/16 in. from the top. The spacing and sizes of stirrups are shown in Fig. 1. They passed under the longitudinal steel, alternate ones enclosing only the two middle bars.

Auxiliary Test Pieces.- Out of the concrete mixed for each T-beam there was made a set of 3 6-in. cubes and 1 6 x 8 x 40 in. plain beam as auxiliary test pieces.

Table 3.

Data on T-beams.

All beams have longitudinal reinforcement of 6 3/4-in. Johnson bars 10 ft. 6 in. long placed as shown in Fig. 1.

	Stirrups.	
No.	Kind.	Spacing inches.
50, 51	6 1/2-in. bars across flange 1/2-in. high steel corrugated bars,	6
55, 56	1/2-in. high carbon corrugated bars,	6
60, 61	1/4-in. high steel corrugated bars,	3
65, 66	1/4-in. mild steel corrugated bars,	3
70, 71	5/8-in. mild steel plain round rods,	6
75, 76	1/2-in. mild steel plain round rods,	6
85,	No stirrups, bars horizontal.	
86, 87	No stirrups.	

METHOD of REINFORCING

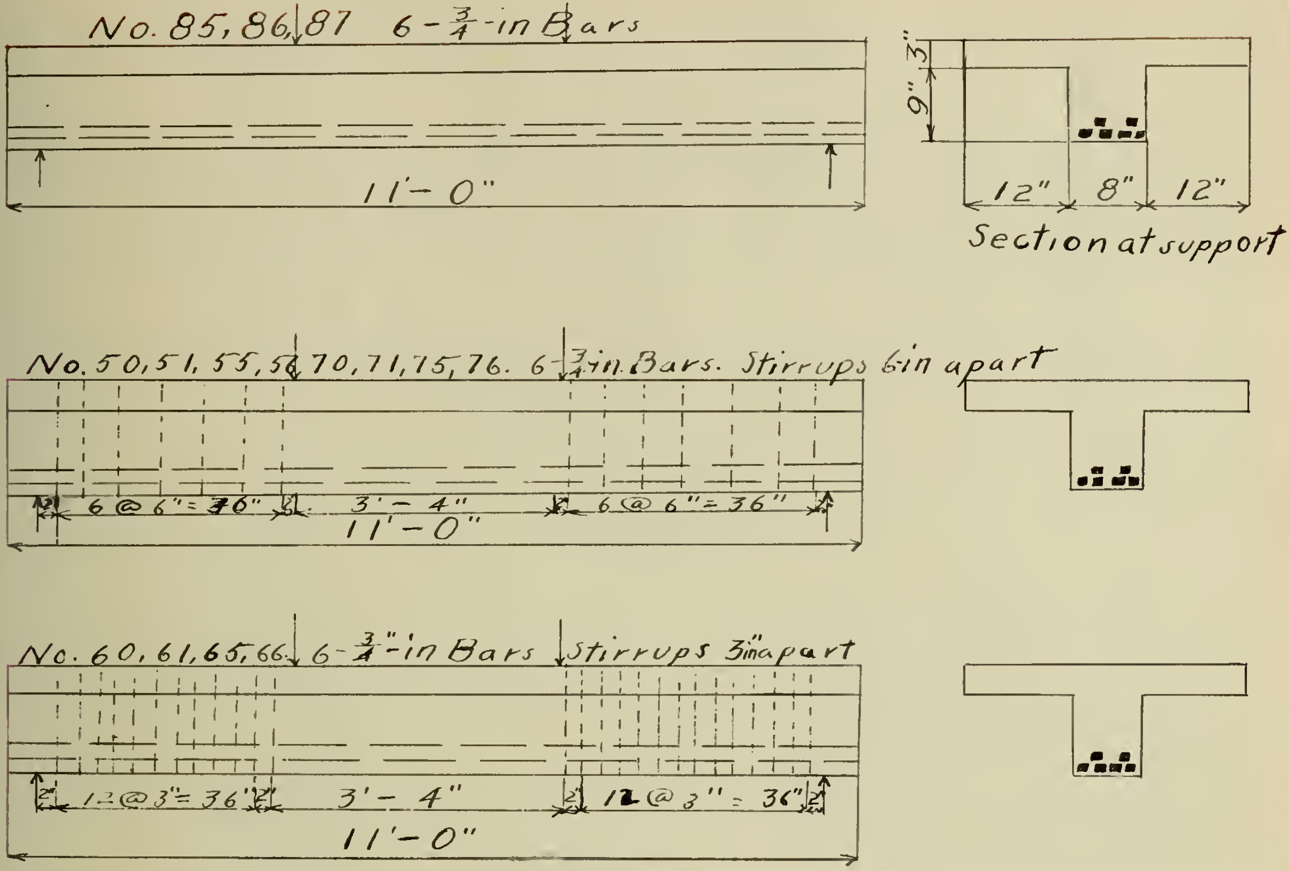
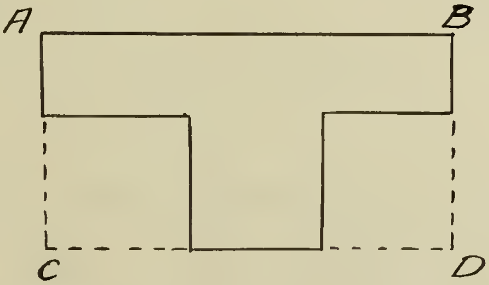
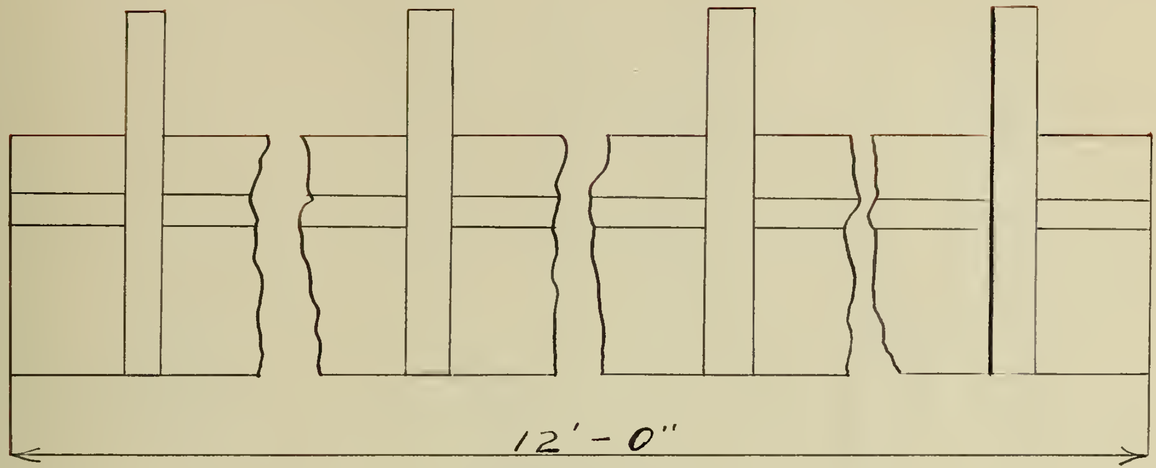

No. 85, 86, 87 6-3/4-in Bars
11'-0"
9"
3"
12"
8"
12"
Section at support
No. 50, 51, 55, 56, 70, 71, 75, 76. 6-3/4-in. Bars. Stirrups 6-in apart
6 @ 6" = 36"
3'-4"
6 @ 6" = 36"
11'-0"
No. 60, 61, 65, 66. 6-3/4"-in Bars Stirrups 3in apart
2"
12 @ 3" = 36"
2"
3'-4"
2"
12 @ 3" = 36"
2"
11'-0"

Fig. No. 1

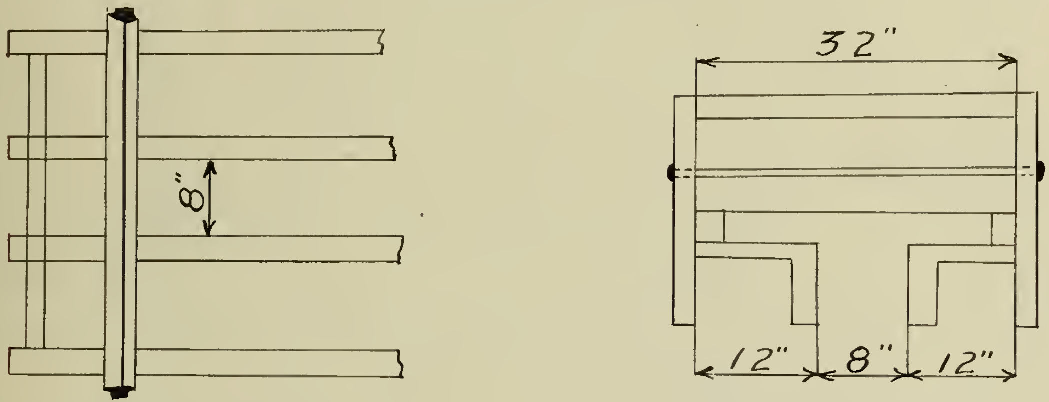


ABCD represents enclosed rectangle

FORMS



Elevation

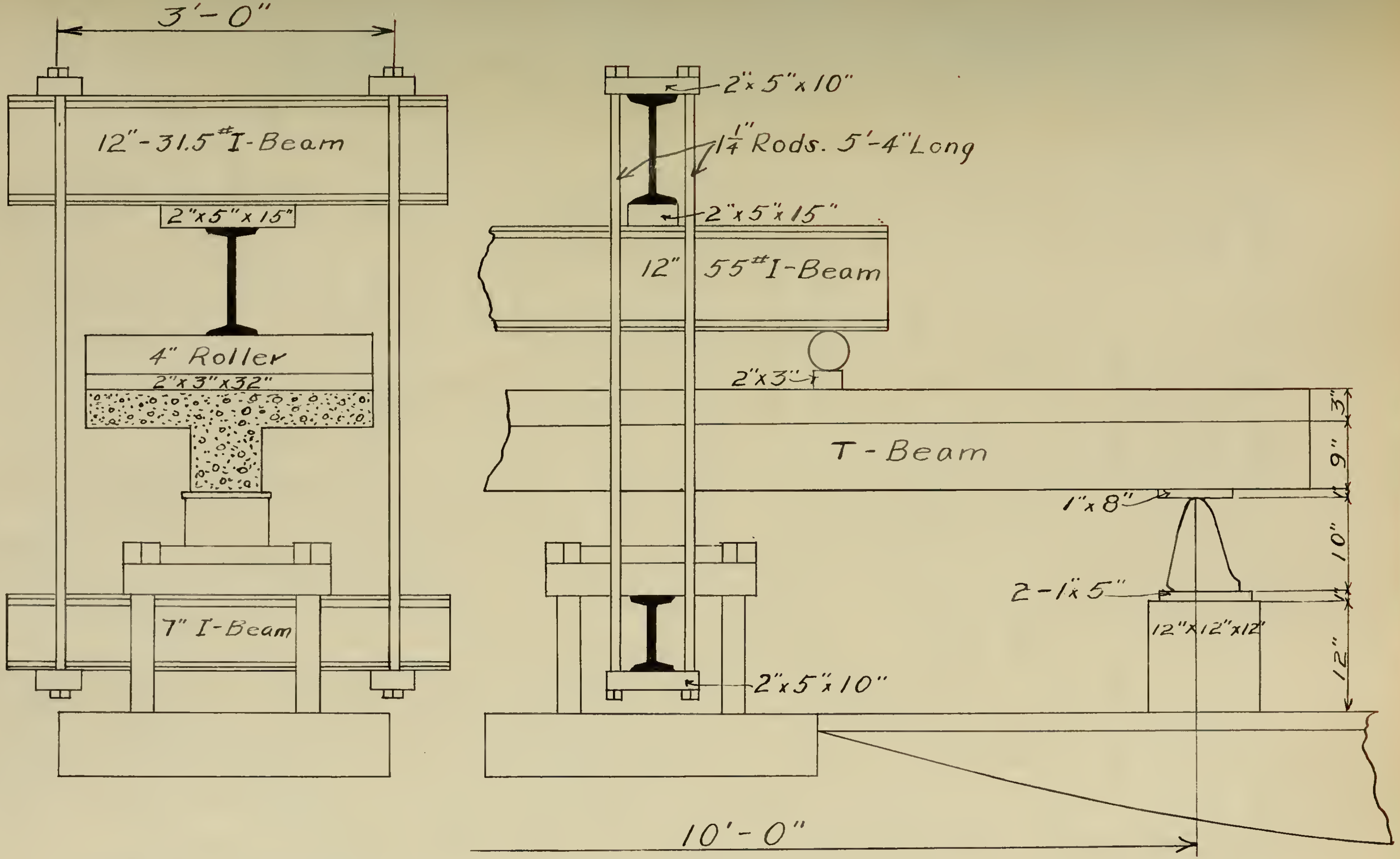


Top View

End View

Fig. No. 2.

(c) Forms.- The above figures show the makeup of forms used in making the beams. 2-in. planks were used for all parts of the forms. Clamps and struts were of 2 x 4-in. pieces. The planks were soaked in water some time before using in order to prevent absorption of water from the concrete. All parts were reversible and by alternating the side which was placed next to the concrete, warping was prevented.


3'-0"
12"-31.5# I-Beam
2"x5"x15"
4" Roller
2"x3"x32"
7" I-Beam
2"x5"x10"
1¼" Rods. 5'-4" Long
2"x5"x15"
12" 55# I-Beam
2"x3"
T-Beam
3"
9"
1"x8"
10"
2-1"x5"
12"x12"x12"
12"
2"x5"x10"
10'-0"

CROSS SECTION

ELEVATION

Fig. 3

(d) Fabrication and Storage.- The concrete was mixed on a large sheet-steel mixing board. The concrete was proportioned by loose volume and then weighed as a check on the proportions. Enough concrete for one T-beam, 3 6-in. cubes, and 1 6 x 8 x 40-in. plain beam was mixed in one batch. The concrete was put in the forms and leveled to a depth of about 1 1/2 in. The longitudinal rods and vertical stirrups were then placed. The longitudinal rods were so placed that the distance from the top of the finished T-beam to the centroid of these rods would be 10 in. The T-beam was built up by putting in 3-in. layers of concrete and tamping and spacing the sides. The forms were taken off after 7 days. The beams were sprinkled twice a day until tested. The temperature of the storage room ranged from 55° to 65° F. The T-beams were tested when about 60 days old.

(e) Methods of Testing.- The beams were loaded as shown in Fig. 3, the points of application of the load being at the 1/3 points of the span. The machine used was the Olsen 200 000-lb. testing machine. The base surfaces of the pedestals upon which the beam rested were curved to permit rocking. The pedestals were 10 ft. apart. Between the pedestals and beam, bearing plates 8 x 1 x 12 in. were used. Two cast-iron bars 2 x 3 x 32 in. extended across the top of the beam at the load points. Upon each of these bars, which were faced on both sides, rested a 4-in. turned steel roller. The load was distributed to these rollers by the apparatus as shown in Fig. 3. To secure an even and uniform bearing, plaster of paris was put between the

bars and the beam. The two yokes holding the extensometers were put on with points touching both the top and bottom of the beam, one 15 in. each side of the center line of the span. They were connected by rods as described later in Art. (f).

Diagram For Obtaining Deformations

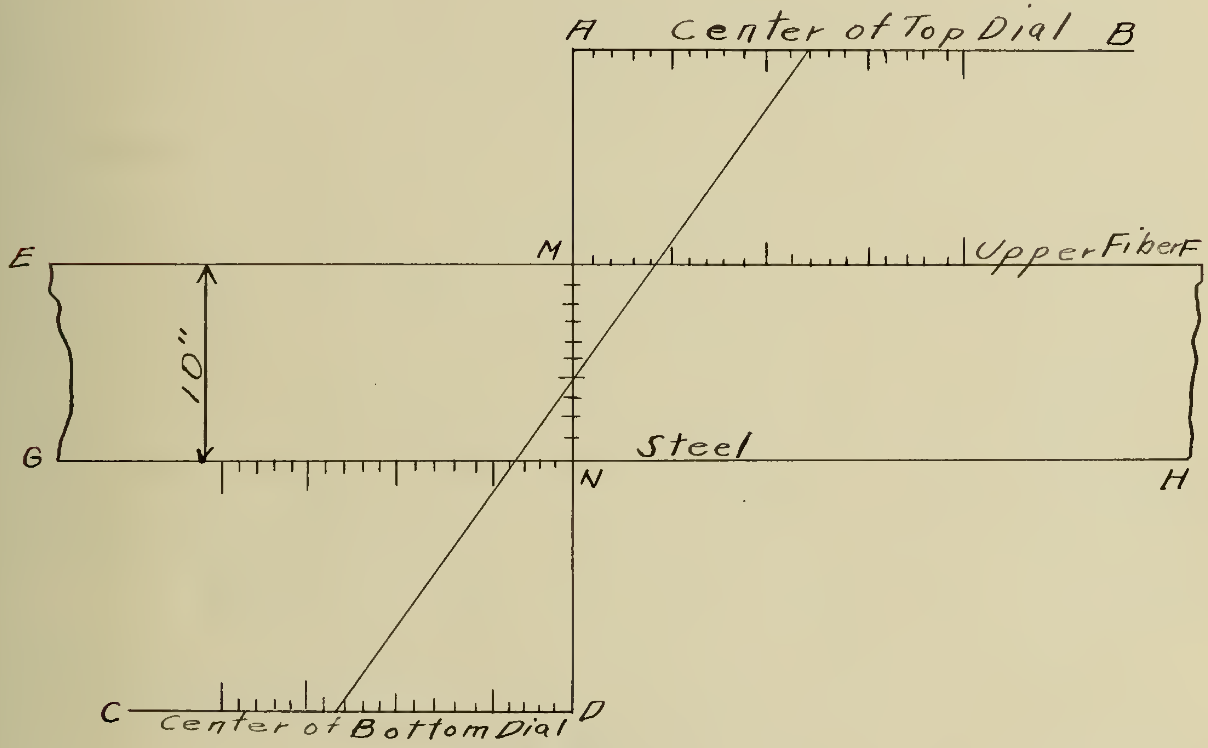


Fig. No. 4.

The deformations in the upper fiber and steel were obtained by calculations made from readings taken with these extensometers. The average of the two upper extensometer readings was laid off to a scale along the line A-B on above diagram. The average of the two lower extensometer readings was laid off along the line C-D. The distance between these two lines represented to convenient scale the distance between

the centers of the upper and lower dials. To the same scale A-M represents the distance from the upper fiber to center of the upper dials and N-D the distance from the center of the steel to the center of the lower dials. E-F and G-H are graduated to the same scale as A-B and C-D. A thread stretched across from a point on A-B to a point on C-D representing the corresponding readings of the dial for a certain loading gives the value for the shortening of the upper fiber on E-F and the elongation of the steel on G-H at the points where the thread crosses these lines. The gauge length of the extensometers being 30 in., the values read from G-H and E-F have to be divided by 30 to get the unit deformation. The line A-D was graduated so that each division represented one per cent of the depth from the top of the beam and the point where the thread crossed this line gave the position of the neutral axis.

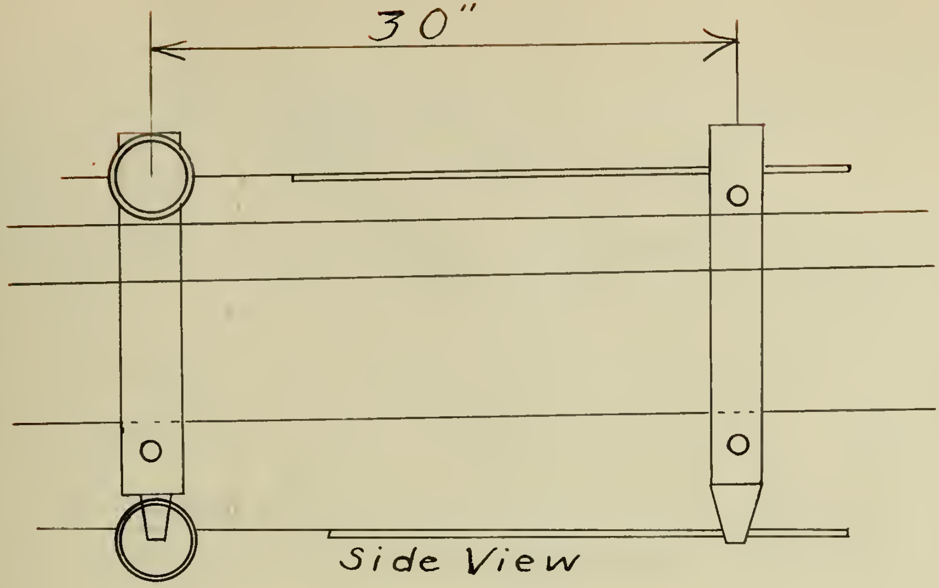
The center deflections were read by means of a scale attached to the middle of the side of the web. A thread extended along the side of the web from points above the supports and the movement of this thread over the scale gave the deflection.

The load was increased in increments of from 3 000 lb. to 5 000 lb. Between increments the machine was stopped to take readings.

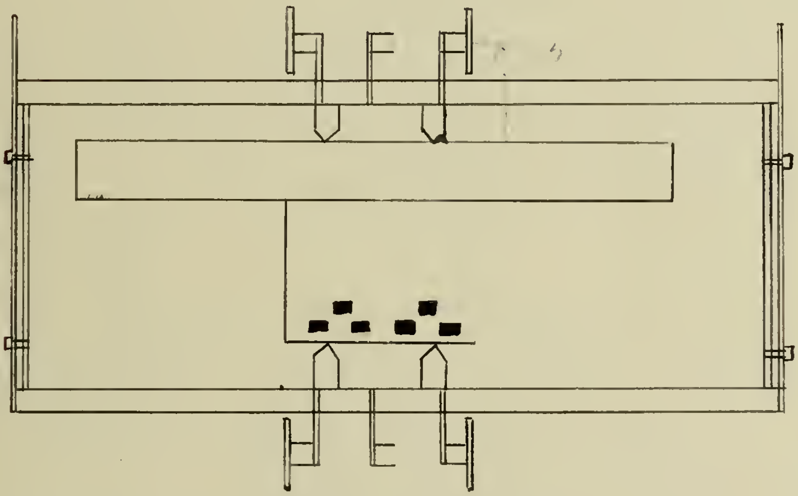
(f) Description of Apparatus.- The extensometer device used is shown in Fig. 5. The mountings were designed and made in the work-shop of the Laboratory of Applied Mechanics of the University of Illinois. It consisted of two yokes on one of which are four Johnson extensometer dials. The other was provided with fixed pins corresponding to the positions of the rollers for the dials. The yokes were placed 30 in. apart and symmetrically with the middle of the span. On each dial is a large pointer fixed at the center on a pinion which runs through the dial and is connected to a small roller back of the dial. These rollers were 22 in. apart vertically. The upper ones were 5 in. above the top of the beam. The circumference of each roller was 0.5 in. The dials were 4 in. in diameter and graduated so that the readings were obtained to 0.0001 in. The pins of the second yoke were connected to the rollers by rods laid with a V-shaped notch over the pins and a smooth surface on the rollers. Any movement of the yoke caused the rod to move with respect to the yoke carrying the extensometer and this, by friction, caused the roller to turn, which caused the pointer on the dial to move and thus the readings were obtained.

The apparatus used by Mr. Abrams in testing the stresses across the top of the flange consisted of three microscopes, each having a graduated scale on which the divisions corresponded to 0.0008-in., attached at the lower end. These were spaced 8 in. apart and held in position by a wooden frame with a pin point in each end and this frame was clamped fast to

the flange of the beam. When these were placed in position the microscopes were vertical and came directly over a 1/4-in. square brass rod which was embedded in the top of the flange. On this rod a mark was made and by looking through the microscopes it could be seen by the scale in the microscope how much this mark had moved.



Side View



End View
Fig. No. 5

Extensometer Device

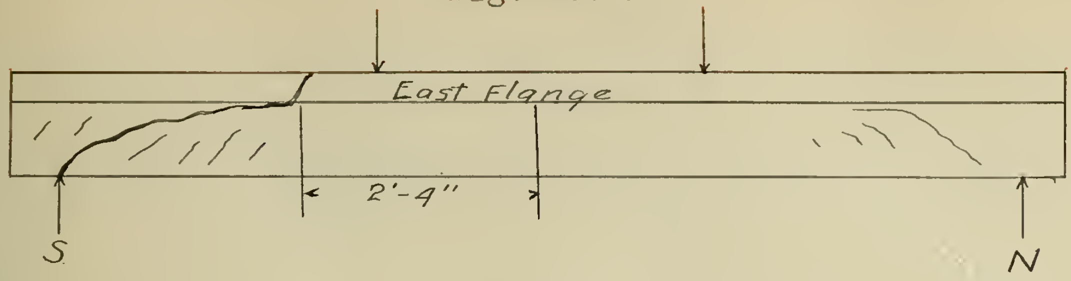
IV. EXPERIMENTAL DATA AND DISCUSSION.

(a) Deflection and Deformation Diagrams.- The curves on the last pages of this thesis represent the deflections of the beams at the center, the deformations of the upper fiber and the steel, and the position of the neutral axis. The curves were plotted from computations made from the readings taken from the Johnson extensometer and from the scale for deflections. The ordinates represent the applied load in pounds and the abscissas the corresponding deflections at the center of the beam, and also corresponding unit-deformations in the upper fiber and steel. A curve showing the variation of the neutral axis was plotted.

For the neutral axis the loads are plotted as abscissas; and for ordinates the per cent of the total depth of beam, that the neutral axis is below the top of the beam.

(b) Phenomena of Tests.- The beam in these tests were uniform in their makeup. The concrete was of good quality and was of the same material and mixture in all cases. The size of each beam was the same; the only difference in the beams being the kind and size of stirrup reinforcement and the spacing of same. The horizontal reinforcement was the same for all the beams.

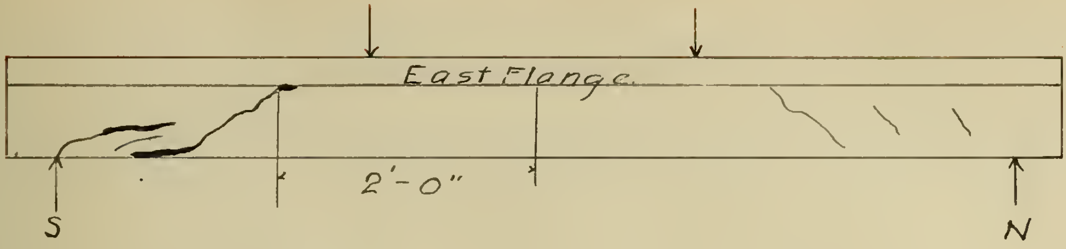
Fig. No. 50.



Beam No. 50. This beam was reinforced with stirrups of 1/2-in. high-steel corrugated bars spaced 6 in. apart.

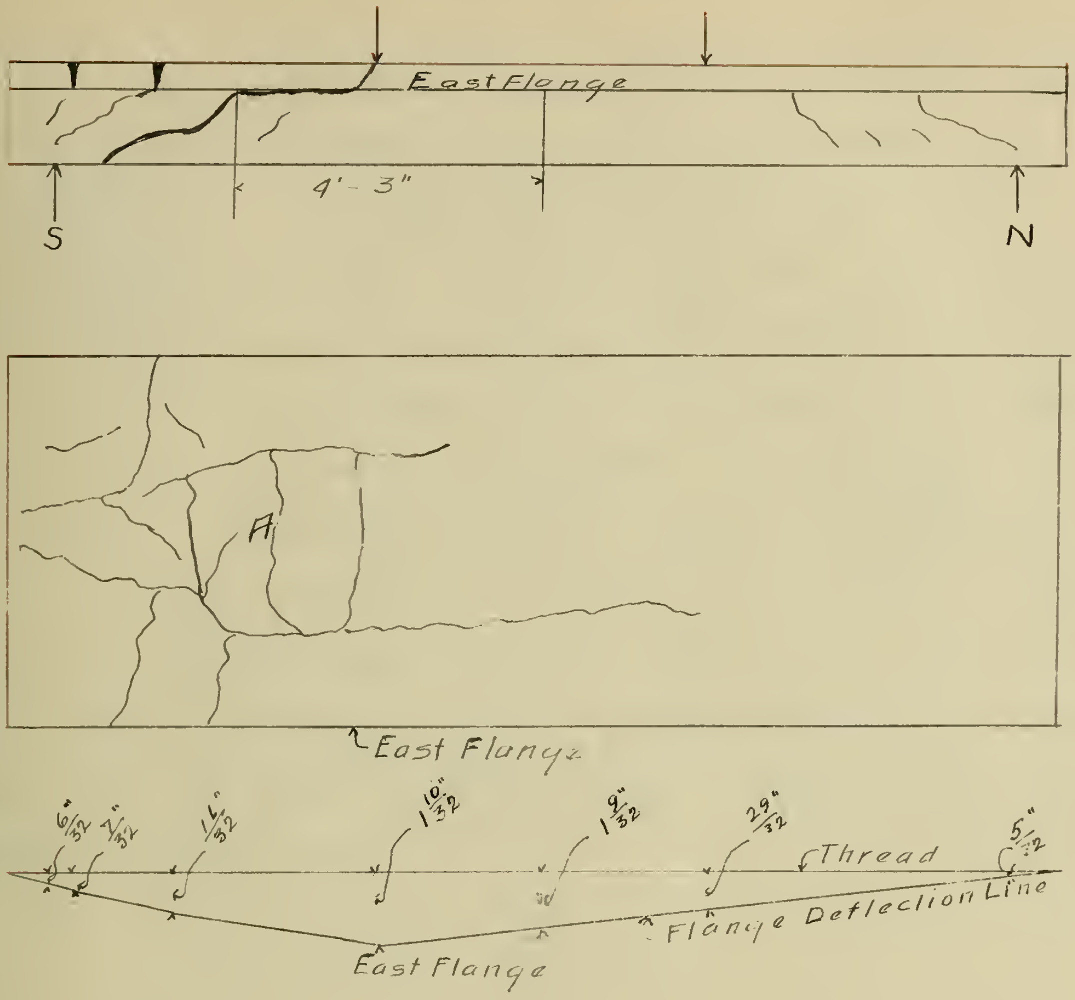
The first crack appeared when the load was 28 000 lb., about 1 1/2 ft. from the south end. This hair-like crack was not very long when first seen, but as the load was increased it grew longer and larger and soon extended diagonally across the web at the support. Others appeared at about 40 000 lb., all of which grew larger and longer as the load was increased. At 47 000 lb. the beam would not support any additional load and failed by diagonal tension in the concrete along the first crack that appeared. The deflection at the maximum load was 0.46 in.

Fig. No. 51.



Beam No. 51 was reinforced the same as Beam No. 50 with stirrups of 1/2-in. high-steel corrugated bars spaced 6 in. apart. A hair-like crack was first seen near the north end at a load of 20 000 lb. Another appeared near the load point on the same end at 21 000 lb. and one on the south end at 22 000 lb. All of these increased in length and grew larger, those on the south end a little faster than the others. The maximum load the beam would stand was 29 000 lb. Failure was along a diagonal crack beginning at the top of the web about 3 ft. from the south end and running diagonally across the web to within about 1 ft. of the support, then followed the horizontal reinforcement to the support. The deflection at the maximum load was 0.30 in.

Fig. No. 55.

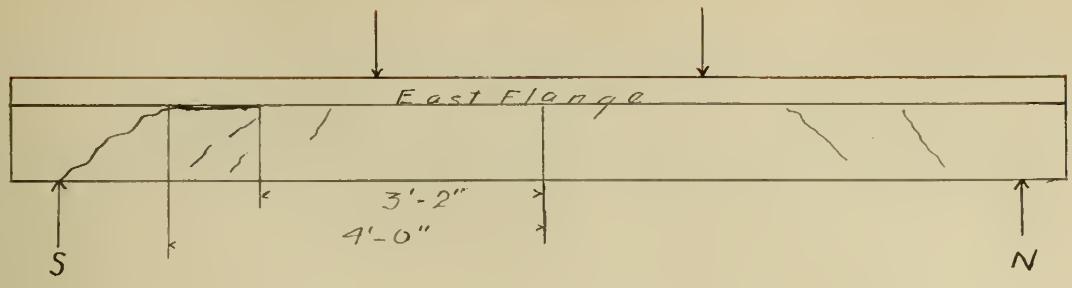

East Flange
4'-3"
S
N
A
East Flange
6/32"
7/32"
1 1/32"
1 10/32"
1 9/32"
29/32"
5/32"
Thread
Flange Deflection Line
East Flange

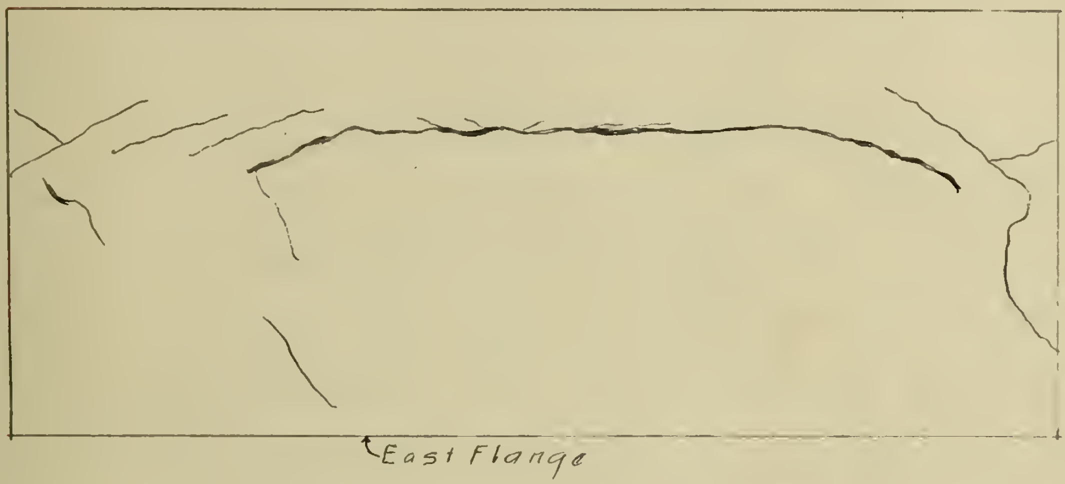
Bean No. 55 was reinforced with 1/2-in. high-carbon corrugated bar-stirrups spaced 6 in. apart.

About 2 ft. from the north end a hair-like crack appeared at a load of 24 000 lb. Between this and 30 000 lb. quite a number of cracks appeared, mostly at the south end. The maximum load was 31 300 lb., failure being by a diagonal crack beginning at the top of the web about 2 ft. from the south end and running to the support. After the maximum was reached the load was permitted to drop back. When about 30 000 lb. a crack on

the under side of the east flange, near the load line, running from the web to the edge of the flange was noticed. On looking on top of the beam it was seen that a slab about 1 1/2 ft. wide and about 2 ft. long had broken loose about 8 or 10 in. from the load line and was bulging up from the rest of the beam. As the load was permitted to drop back it bulged up farther until the loading was stopped. This is marked "A" on the sketch. The deflection curve formed by the edge of the flange was very irregular, as is shown in the sketch. Cracks in the edge of the flange was taken from the horizontal rods near where failure occurred to see if they had slipped, and it was found that they showed no sign of slip. The deflection at the maximum load was 0.54 in.

Fig. No. 56.

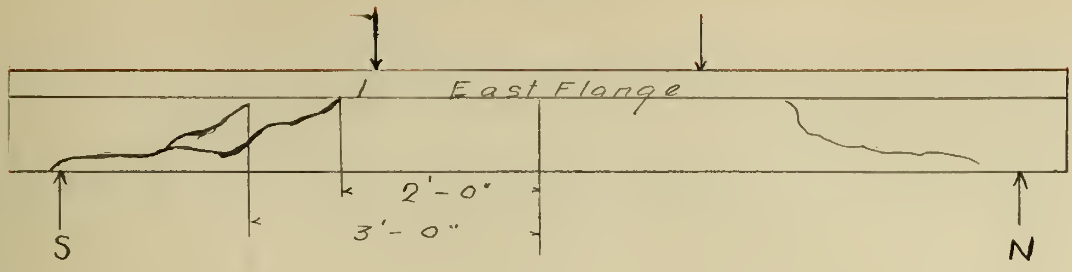




Beam No. 56. The same size reinforcing stirrups were used in this beam as in No. 55; 1/2-in. high-carbon corrugated bars, spaced 6 in. apart.

At a load of 24 000 lb. the first crack was seen about 2 1/2 ft. from the south end. Quite a number of cracks appeared between this and the south support while but two very small cracks appeared on the north end. Failure was by diagonal tension about 1 1/2 ft. from south end at the load of 45 700 lb. The load dropped back after the maximum was reached and when the load was 41 000 lb. a sudden jar was felt and the load fell suddenly to 26 000 lb. On examination it was found that the west flange had cracked loose from the web along the center of the beam but still clung to it at the end, as is shown in sketch. The deflection at the maximum load was 0.55 in.

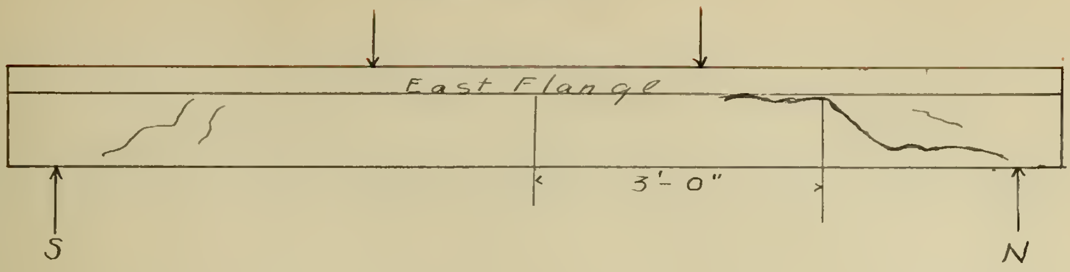
Fig. No. 60.



Beam No. 60. The stirrups in this beam were 1/4-in. high-steel corrugated bars spaced 3 in. apart.

Not many cracks appeared on this beam. The first one was seen in the center of the web about 3 ft. from the north end at a load of 19 000 lb. Soon others appeared. As the load increased the cracks grew longer on both ends and at 25 000 lb. had reached the flange and the line of horizontal reinforcement. At 19 400 lb. a crack was seen about 2 ft. from the south end. At 25 000 lb. another appeared about 1 ft. nearer the center of the beam. These two ran diagonally down across the web and joined together at the line of the horizontal reinforcement. The failure was along this line at a load of 26 100 lb. The deflection at the maximum load was 0.35 in.

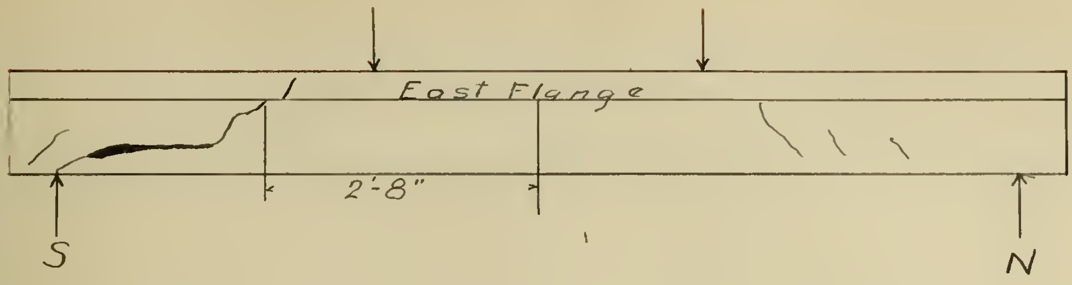
Fig. No. 61.



Beam No. 61. The stirrups in this were the same as those in No. 60; 1/4-in. high-steel corrugated bars spaced 3 in. apart.

The first crack was seen in the center of the web about 2 ft. from the north end at a load of 19 000 lb. When the load was increased it ran up to the flange and down to the line of horizontal reinforcement. On the south end several cracks appeared between 24 000 lb. and 28 000 lb. The maximum load was 33 000 lb. and the corresponding deflection was 0.38 in.

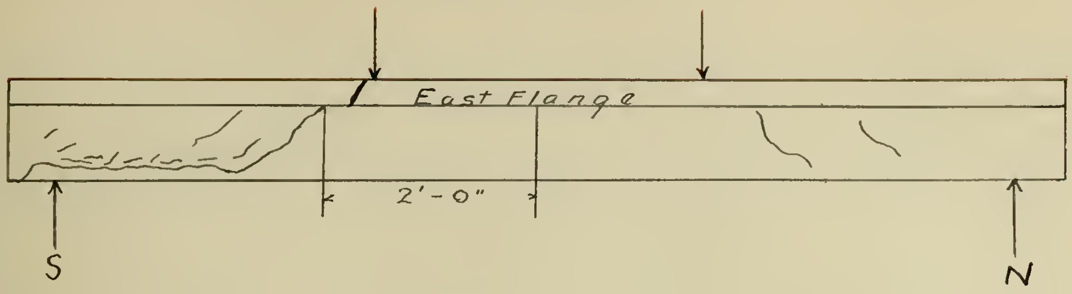
Fig. No. 65.



Beam No. 65. The stirrups in this beam were 1/4-in. mild-steel corrugated bars spaced 3 in. apart.

Two cracks were seen about the same time 2 ft. and 3 ft. from the north end of the beam, the load being 30 000 lb. At about 35 000 lb. a crack appeared on the south end about the center of the web. At 40 000 lb. one appeared a little nearer the end. The two united as the load was increased and the failure was along the line formed by these two cracks at a load of 43 800 lb. The deflection at the maximum load was 0.47 in.

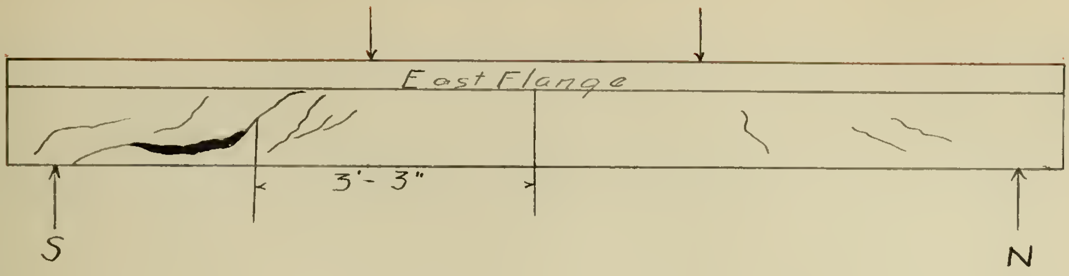
Fig. No. 66.



Beam No. 66. The reinforcement was 1/4-in. mild-steel corrugated bar-stirrups spaced 3 in. apart.

When the load was about 19 000 lb. a hair-like crack was seen 2 1/2 ft. from the north end at the same time one was seen about 3 ft. from the south end. Not many more cracks appeared. Failure was along the first crack seen on the south end. The maximum load was 34 000 lb. and the deflection at 30 000 lb. was 0.24 in.

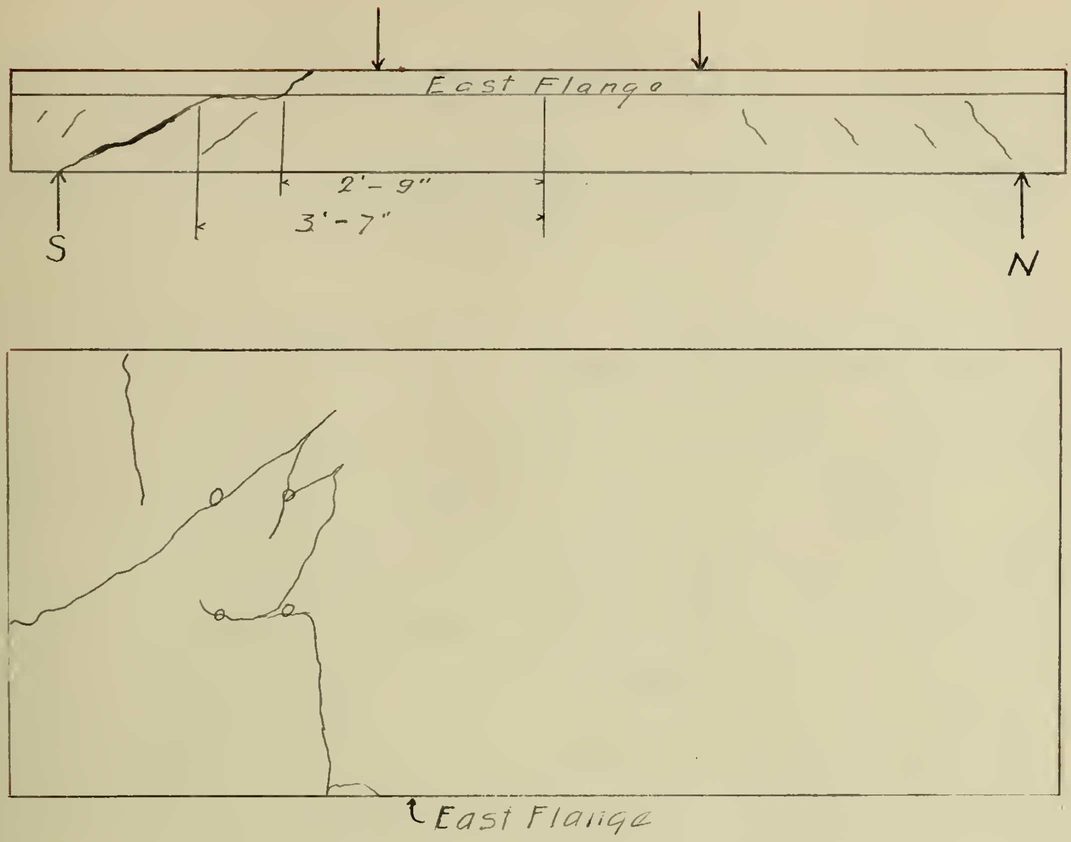
Fig. No. 70.



Beam No. 70. The stirrups in this beam were 5/8-in. mild-steel round rods spaced 6 in. apart, and were exposed on both sides of the web.

Because of the crippling of the small I-beams running beneath the head of the testing machine the maximum was not reached during the first test but the load was released after reaching 48 000 lb. and new I-beams placed beneath the head of the testing machine. During the first test hair-line cracks appeared near each end at about 37 000 lb. Several others appeared between 37 000 lb. and 48 000 lb. When the load was again applied these reopened at about 25 000 lb. and failure occurred along a diagonal crack about 2 ft. from the south end. The concrete chipped off considerably along the horizontal reinforcing line. The maximum load was 58 100 lb. and the corresponding deflection was 0.82 in.

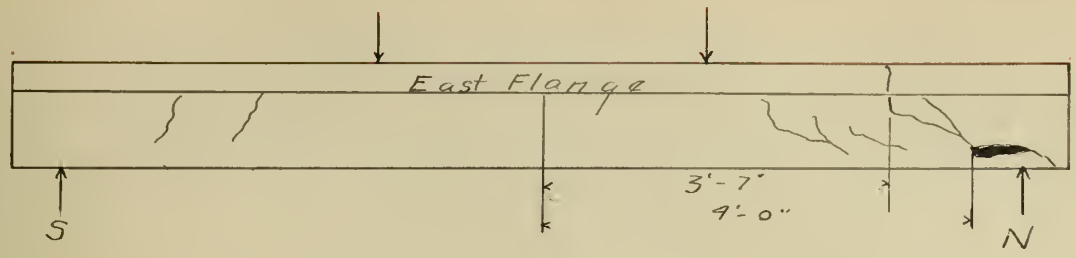
Fig. No. 71.



Beam No. 71. The reinforcing stirrups were 5/8-in. plain round mild-steel rods spaced 6 in. apart. The ends of some of these projected above the top of the beam about 1/8 to 1/4 in.

The first crack appeared about 3 ft. from the north end when the load was about 21 000 lb., one appeared about 2 ft. from the south end at 23 000 lb. which ran in a diagonal direction from the flange to the support. The failure occurred along this crack at 42 000 lb. The top of the beam cracked considerably between the south support and load line, as shown in sketch. The deflection at 55 000 lb. was 0.42 in.

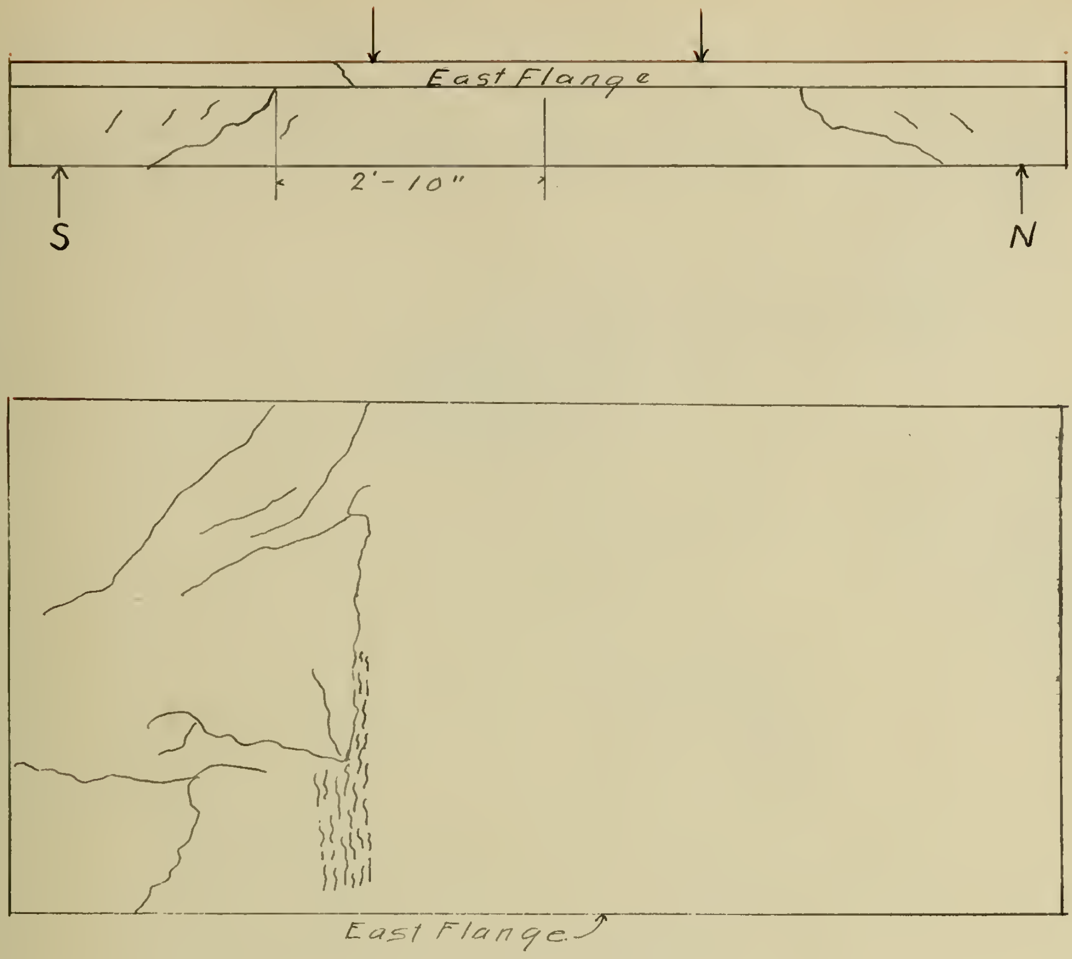
Fig. No. 75.



Beam No. 75. The stirrups in this beam were 1/2-in. mild-steel plain round rods spaced 6 in. apart. Each prong was bent outward and extended 6 in. into the flange.

Only two small cracks appeared on the south end of this beam, one when the load was 30 000 lb. about 2 1/2 ft. from the south end, the other at 35 000 lb. about 1 3/4 ft. from the same end. Cracks appeared at 30 000 lb. about 2 ft. from the north end. Others appeared as load was increased. Failure was by diagonal tension about 1 1/2 ft. from the north end. The concrete scaled off considerably along the line of the horizatal reinforcement. The maximum load was 49 200 lb. and the corresponding deflection 0.47 in.

Fig. No. 76.

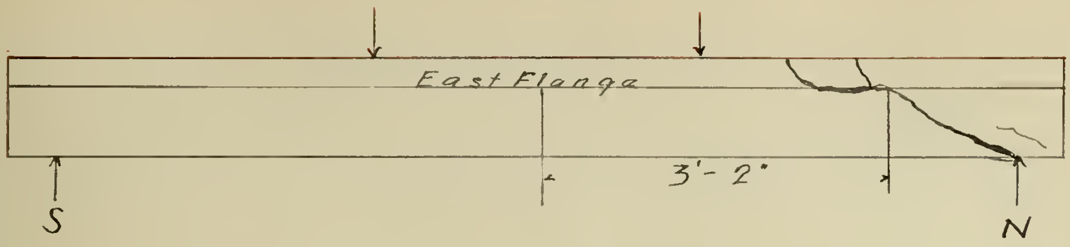


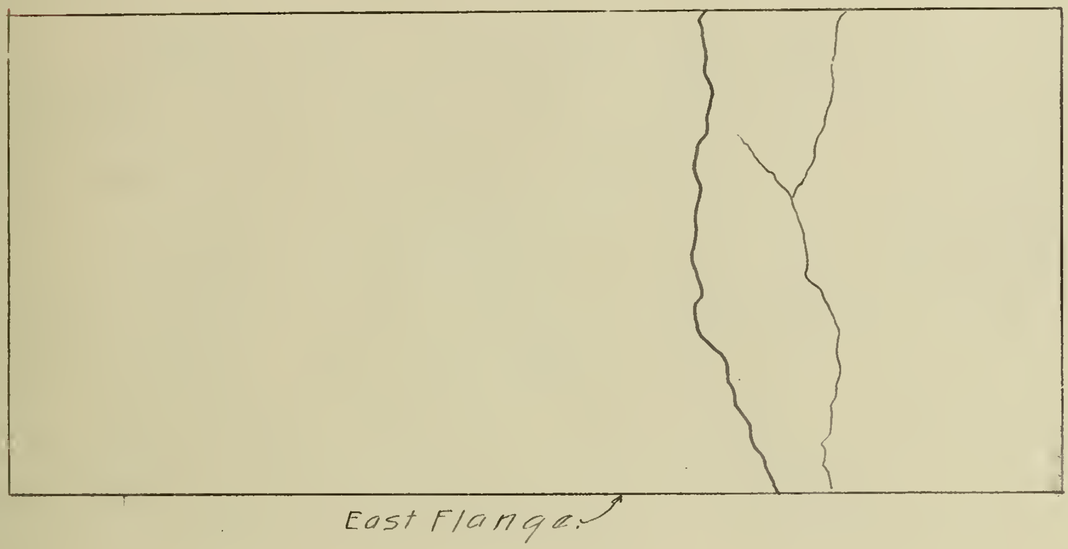
Beam No. 76. The stirrup reinforcement was the same as for T-beam No. 75; 1/2-in. plain round rods spaced 6 in. apart. Each prong was bent outward and extended 6 in. into the flange.

A few short hair-like cracks appeared on north end. The first crack was noticable at about 30 000 lb. Quite a number appeared on south end. Failure came along a diagonal crack about 1 2/3 ft. from the south end, with a load of 51 200 lb. As the load dropped back the top began to scale off and crack considerably and near the load line it chipped up and crushed together as if very much compressed at that place.

This is shown in the sketch. The deflection at the maximum load was 0.58 in.

Fig. No. 85.

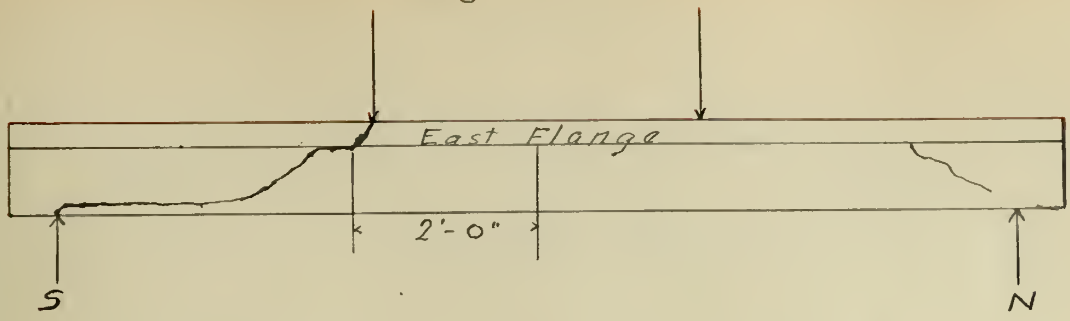




Beam No. 85. There were no stirrups in this beam, only the horizontal reinforcement. The extensometers were not put on this beam therefore no deformation results were obtained.

No cracks appeared; when the load was 30 000 lb. it suddenly broke in a diagonal line which began just under the flange about 2 ft. from the north end and ran diagonally downward to the end. The top cracked as shown in the sketch. The deflection at 27 000 lb. was 0.14 in.

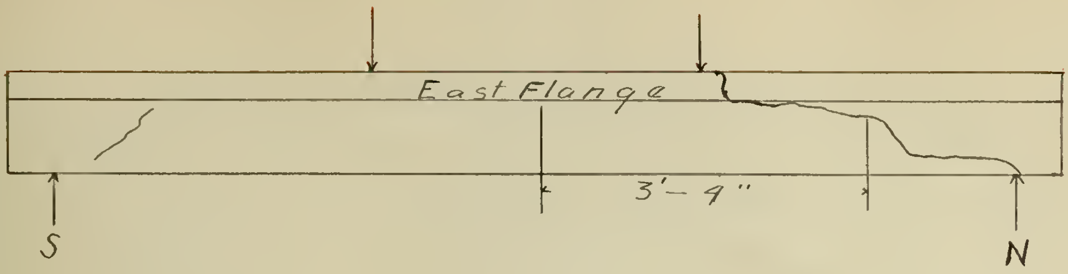
Fig. No. 86.



Beam No. 86. There were no stirrups used for reinforcement in this beam. The longitudinal reinforcement was the same as in the previous beams.

A crack was seen about 3 ft. from the south end at 21 000 lb. and one little hair-like crack appeared on the north end at 23 000 lb. The beam broke like No. 85, along the first crack seen at 26 200 lb. The deflection at 24 000 lb. was 0.17 in.

Fig. No. 87.



Beam No. 87. There were no stirrups in this beam. Hair-like cracks were seen in the center of the web about 2 ft. from each end when the load was 16 000 lb. The beam broke along the line seen on the north end just like Beams No. 85 and 86, at a load of 17 600 lb. The deflection at 15 000 lb. was 0.08 in.

(c) Tension in Steel.- The curves plotted gave no indication that the beams failed by tension in the steel. In Table 4 are given the stresses as calculated in the reinforcement at the maximum load. These stresses were calculated from the formula M = 0.86 Afd, in which A = area of the cross section of longitudinal reinforcement, f = tensile stress per unit of area in the longitudinal reinforcement, d = distance from the compressive face to the centroid of the longitudinal reinforcement, and M = resisting moment at the given section. The maximum load included the applied load and weight of apparatus.

The elastic limit of the steel, as determined by tests upon specimens of the steel used in the various beams, was from 20% to 200% greater than the stresses in the steel as computed from the maximum loads which the beams carried.

(d) Web Stresses.- The load which the beam will carry is much increased by the web reinforcement. The stress developed in the stirrups under maximum load varied from 7032 lb. to 10 656 lb. The shear in the web was 150 to 444 lb. per sq. in., and under the maximum load varied from 150 to 444 lb. per sq. in. The bond on the horizontal reinforcement developed at the maximum load varied from 67 to 197 lb. per sq. in. In general the strength of the beams depended upon the spacing of the reinforcement. In Table 5 are given the values of the vertical shearing unit stresses for the maximum load calculated by equation $v = \frac{V}{b'\ d'}$.

V = total end shear at maximum load.

v = vertical shearing stress per unit area.

b' = breadth of stem of T-beam.

d' = distance from the center of the longitudinal reinforcement to the center of gravity of the compressive stresses.

v' = vertical shearing stress in pounds per square inch where first crack appeared.

(e) Beam Deflection.- The center deflection of the beam under a load of 40 000 lb. ranged from 0.28 in. to 0.38 in. For other deflections see tables that come later.

(f) Neutral Axis.- The position of the neutral axis varied considerable for different beams, the average of all the beams was about 50% of the effective depth from the top of the beam under loads of 25 000 lb. to 50 000 lb. The neutral axis of the individual beams also varied. The curves show at the beginning an irregular adjustment stage.

(g) Beam and Cube Tests.- Table 7 gives the results of the tests of the 6 x 8 x 40-in. plain concrete beams and 6-in. cubes, which were made from concrete from the same batch as the T-beams of the corresponding number.

Table 4.

Results of Tests of T-Beams.
M = 0.87 Afd.

No.	Web Reinforcement Stirrups. Kind	Maximum Load pounds Applied Load	Maximum Load pounds Total Load	Bending Moment lb.-in.	Stress in Steel at Maximum Load lb. per sq. in.
50	1/2-in. high-steel corrugated bars spaced 6 in.	47 000	50 000	1,000,000	34 500
51	do.	29 000	32 000	640,000	22 000
55	1/2-in. high-carbon corrugated bars spaced 6 in.	31 300	34 300	686,000	23 600
56	do.	45 700	48 700	974,000	33 500
60	1/4-in. high-steel corrugated bars spaced 3 in.	26 100	29 100	582,000	20 000
61	do.	33 000	36 000	720,000	24 800
65	1/4-in. mild-steel corrugated bars spaced 3 in.	43 800	46 800	936,000	32 000
66	do.	34 000	37 000	740,000	25 500
70	5/8-in. mild-steel plain round bars spaced 6 in.	58 100	61 100	1,222,000	42 200
71	do.	42 000	45 000	900,000	31 000
75	1/2-in. mild-steel plain round bars spaced 6 in.	49 200	52 200	1,044,000	36 000
76	do.	51 200	54 200	1,084,000	37 500
85	No stirrups	30 400	33 400	668,000	23 000
86	do.	26 200	29 200	584,000	20 100
87	do.	17 600	20 600	412,000	14 200

Table 5.

Web Stresses.

No.	At First Diagonal Crack		At Maximum Load		Total Stress in one prong of stirrup. pounds	Manner of Failure
	Total Load pounds.	lb. per sq. in. V′	Bond U lb. per sq. in.	Shear V lb. per sq. in.		
50	31 000	225	161	364	8 736	Diagonal Tension.
51	23 000	168	103	233	5 592	do.
55	24 000	175	111	293	7 032	do.
56	27 000	196	157	370	9 400	do.
60	22 000	160	94	211	2 532	do.
61	22 000	160	116	262	3 840	do.
65	33 000	240	151	341	4 092	do.
66	22 000	160	120	269	3 278	do.
70	40 000	291	197	444	10 656	do.
71	24 000	175	145	328	7 872	do.
75	33 000	240	168	379	9 096	do.
76	33 000	240	175	393	9 432	do.
85	33 400	243	108	243	5 832	do.
86	24 000	175	94	213	5 112	do.
87	19 000	138	67	150	3 600	do.

Table 6.

Stresses in Stirrups.

No.	Kind and Spacing of Stirrups	Total Stress on each prong of stirrup. pounds	Unit Stress on each prong of stirrup lb. per sq.in.	Bond lb. per sq. in.
50	1/2-in. high-steel corrugated bars spaced 6 in. apart.	8 736	34 900	874
51	do.	5 592	22 368	559
55	1/2-in. high-carbon corrugated bars spaced 6 in. apart.	7 032	28 100	703
56	do.	9 400	37 600	940
60	1/4-in. high-steel corrugated bars spaced 3 in. apart.	2 532	40 512	506
61	do.	3 840	61 500	768
65	1/4-in. mild-steel corrugated bars spaced 3 in. apart.	4 092	65 450	818
66	do.	3 278	52 450	656
70	5/8-in. mild-steel plain round bars spaced 6 in. apart	10 656	34 800	1 088
71	do.	7 872	25 700	803
75	1/2-in. mild-steel plain round bars spaced 6 in. apart.	9 096	46 000	1 159
76	do.	9 432	48 000	1 201
85	No stirrups.			
86	No stirrups.			
87	No stirrups.			

Bond on stirrups computed by dividing total stress on each prong by the product obtained by multiplying the circumference of each stirrup by the effective depth, which was taken as 5 inches.

Table 7.

Results of 6-in. Cube Tests.
1:2:4 Concrete

Concrete as in T-beam No.	Age at Test days	Proportion by Weight	Unit Load lb. per sq. in.
50	68	1 - 2.55 - 4.06	1960 1725 1870
51	51	1 - 2.44 - 4.25	1130 1010 1160
55	51	1 - 2.63 - 4.31	1070 1180 1110
56		1 - 2.52 - 4.34	
60	57	1 - 2.47 - 4.24	900 920 960
61		1 - 2.44 - 4.14	
65	61	1 - 2.46 - 4.43	2220 2130 2340
66	58	1 - 2.42 - 4.33	1590 1430 1770
70	61	1 - 2.40 - 4.18	1860 1730 1880
71	57	1 - 2.67 - 4.32	1525 1550 1640
75	61	1 - 2.40 - 3.99	1530 1440 1340

Table 7 continued.

76	68	1 - 2.41 - 4.07	2180 2160 2160
85	61	1 - 2.62 - 4.36	2506 2411 2292
86	67	1 - 2.41 - 4.11	1710 1835 1410
87	69	1 - 2.44 - 4.21	1710 1665 1790

Table 8.

Results of Tests of 6 x 8 x 40-in. Plain Concrete Beams.
Span 36 inches.

Concrete as in T-beam No.	Age in Days at Test.	Applied Load. pounds.	Modulus of Rupture pounds.	Where failed.
50	68	3 360	315	Between center and load point
51	58	2 760	259	Load point.
55	58	2 690	252	Load point.
56	57	3 270	306	Near center.
60	57	1 550	145	Center.
61	56	3 630	340	Load point.
65	73	3 640	341	Between center and load point
66	65	3 970	372	Center.
70	70	2 890	271	Center.
71	69	2 970	279	
75	70	2 650	248	Between center and load point
76	64	2 940	276	
85	126	4 850	455	Center.
86	64	3 130	293	Center.
87	49	2 480	233	

Table 9.

(h) Summary.

No.	Kind of Reinforcement	Loaded at First Visible Cracks. pounds.	Maximum Applied Load. pounds	Manner of Failure
50	Stirrups 1/2-in. high-steel corrugated bars spaced 6 in. 6—3/4-in. corrugated bars placed horizontal.	31 000	50 000	Diagonal Tension.
51	do.	23 000	32 000	do.
55	Stirrups 1/2-in. high-carbon corrugated bars spaced 6 in. 6—3/4-in. corrugated bars placed horizontal.	24 000	34 300	do.
56	do.	24 000	48 700	do.
60	Stirrups 1/4-in. high-steel corrugated bars spaced 3 in. 6—3/4-in. corrugated bars placed horizontal.	22 000	29 100	do.
61	do.	19 000	36 000	do.
65	Stirrups 1/4-in. mild-steel corrugated bars spaced 3 in. 6—3/4-in. corrugated bars placed horizontal.	33 000	46 800	do.
66	do.	22 000	37 000	do.
70	Stirrups 5/8-in. mild-steel plain round rods spaced 6 in. 6—3/4-in. corrugated bars placed horizontal.	40 000	61 100	do.
71	do.	24 000	45 000	do.
75	Stirrups 1/2-in. mild-steel plain round rods spaced 6 in. and bent out into web 6 in. 6—3/4-in. corrugated bars placed horizontal.	33 000	52 200	do.
76	do.	33 000	54 200	do.
85	No stirrups. 6—3/4-in. corrugated bars horizontal	No cracks	33 400	do.
86	do.	24 000	29 200	do.
87	do.	19 000	20 600	do.

V. CONCLUSIONS.

1. The strength of the beam is much increased by using stirrups.

2. The stirrups that were bent out into the web were more effective than others.

3. The stirrups of smaller area and close spacing did not show any material difference in results than those of larger area and greater spacing.

4. The full compressive strength of the concrete at the most remote fiber was not developed in any case.

5. The steel in the longitudinal reinforcement was not stressed beyond the elastic limit.

6. The diagonal tension cracks appeared in the beams with vertical stirrups at about the load at which beams without stirrups broke.

VI. TABLES.

On the following pages are given the original readings and a part of the derived values for beams on which extensometer readings were taken. The applied load in pounds, not including weight of the beam or apparatus used to transfer the load to the 1/3 points, is given in the first column. The second column in the original data tables gives the original readings of the deflection in inches. The second column of the computed data tables gives the deflections in inches from the position of zero load. In the four columns headed "Extensometer Readings" the original readings of the extensometers are given. In the two columns headed "Extensometer Readings" in the computed data tables are the means of the upper and lower readings. In the two columns headed "Deformations" are given the unit deformations in the upper fiber and the steel. The column marked "K" gives the position of the neutral axis in the per cent of the depth of beam from the upper fiber obtained from the extensometer readings.

Photographs.- The three photographs shown were chosen because they represent the usual manner of failure of the T-beams tested. T-beam No. 50 failed by diagonal tension, numerous cracks appearing between the load point and the support. T-beam No. 55 failed by diagonal tension but after the maximum load was reached the part of the flange raised up causing the cracks in the flange to open at the top as if the flange were in tension.

T-beam No. 85 failed by diagonal tension and the photograph shows the crack along which it failed.

Original Data.

Applied Load pounds	Center Deflections inches	Extensometer Readings inches Lower Dials		Upper Dials	
	T-Beam No. 50.				
500	2.36	.2000	.0000	.0000	.0000
5 000	2.38	.2000	.0000	.0040	.0034
10 000	2.40	.2004	.0018	.0088	.0079
15 000	2.43	.2008	.0082	.0140	.0132
20 000	2.48	.2012	.0151	.0193	.0184
25 000	2.52	.2022	.0228	.0239	.0240
30 000	2.56	.2041	.0273	.0310	.0300
35 000	2.62	.1982	.0365	.0401	.0361
40 000	2.68	.1982	.0434	.0476	.0433
45 000	2.76	.1990	.0492	.0558	.0472
47 000	2.82	.2055	.0534	.0632	.0411
40 000	3.08	.2149	.0660	.0728	
35 000	3.20	.2149	.0640	.0690	
		In the [illegible]			
	T-Beam No. 51.				
1 000	1.54	.0000	.0000	.0000	.0000
5 000	1.57	.0038	.0030	.0037	.0035
10 000	1.60	.0088	.0085	.0099	.0085
15 000	1.64	.0178	.0169	.0146	.0141
20 000	1.68	.0304	.0248	.0196	.0202
25 000	1.75	.0393	.0291	.0260	.0256
29 000	1.84	.0420	.0371	.0330	.0311
25 000	1.92	.0411	.0378	.0320	.0297
20 000	2.03	.0397	.0370	.0317	.0243
	T-Beam No. 55.				
400	2.56	.0000	.0000	.0000	.0000
5 000	2.59	.0031	.0000	.0043	.0044
10 000	2.63	.0070	.0052	.0090	.0100
15 000	2.68	.0084	.0060	.0155	.0155
20 000	2.74	.0135	.0100	.0226	.0225
25 000	2.83	.0255	.0183	.0300	.0297
30 000	2.97	.0370	.0264	.0380	.0377
31 300	3.10	.0425	.0304	.0444	.0416
22 000	3.20	.0463	.0262	.0520	.0401
15 000	3.38	.0461	.0186	.0500	.0350
12 000	3.49	.0450	.0163	.0490	.0322

Original Data, continued.

T-Beam No. 56.

1 000	1.85	.0000	.0000	.0000	.0000
5 000	1.87	.0000	.0054	.0036	.0030
10 000	1.90	.0028	.0129	.0073	.0077
15 000	1.93	.0122	.0208	.0138	.0132
20 000	1.98	.0188	.0278	.0196	.0191
25 000	2.02	.0240	.0339	.0205	.0250
30 000	2.07	.0305	.0435	.0319	.0314
35 000	2.12	.0310	.0520	.0384	.0367
40 000	2.19	.0400	.0567	.0453	.0440
45 000	2.32	.0450	.0661	.0537	.0521
45 700	2.40	.0530	.0674	.0550	.0535
26 000	2.55				

T-Beam No. 60.

1 000	1.30	.0000	.0000	.0000
5 000	1.33	.0027	.0024	.0035
10 000	1.36	.0092	.0088	.0091
15 000	1.40	.0175	.0150	.0153
20 000	1.46	.0280	.0234	.0221
25 000	1.54	.0365	.0305	.0295
26 100	1.65	.0395	.0310	.0310
20 000	1.72	.0392	.0281	.0273
14 700		.0308	.0214	.0219

T-Beam No. 61.

1 000	1.82	.0000	.0000	.0000	.0000
5 000	1.83	.0055	.0010	.0038	.0038
10 000	1.87	.0120	.0083	.0091	.0090
15 000	1.91	.0178	.0145	.0144	.0149
20 000	1.96	.0248	.0220	.0221	.0214
25 000	2.00	.0316	.0330	.0278	.0280
30 000	2.09	.0315	.0418	.0349	.0356
33 000	2.20	.0362	.0435	.0392	.0410
24 000	2.27	.0360	.0428	.0313	.0335

T-Beam No. 65.

600	1.72	.0000	.0000	.0000	.0000
5 0000	1.75	.0010	.0000	.0029	.0018
10 000	1.78	.0021	.0000	.0072	.0053
15 000	1.81	.0030	.0011	.0121	.0102
20 000	1.85	.0070	.0071	.0179	.0154
25 000	1.89	.0132	.0114	.0230	.0205
30 000	1.94	.0342	.0168	.0287	.0259
35 000	2.00	.0350	.0228	.0344	.0319
40 000	2.05	.0424	.0311	.0409	.0383
43 800	2.19	.0500	.0319	.0350	.0310
30 000	2.29	.0500	.0320	.0330	.0300
28 000		.0494	.0312	.0313	.0282

T-Beam No. 66.

1 200	1.50	.0000	.0000	.0000	.0000
5 000	1.51	.0047	.0010	.0035	.0020
10 000	1.54	.0067	.0074	.0091	.0075
15 000	1.58	.0166	.0170	.0145	.0128
20 000	1.63	.0172	.0226	.0207	.0183
25 000	1.68	.0225	.0312	.0273	.0249
30 000	1.74	.0325	.0400	.0341	.0320
34 000					
19 300		.0367	.0347	.0269	.0450
15 000		.0328	.0310	.0221	.0400

T-Beam No. 70.

1 500	1.70	.0000	.0000	.0000	.0000
5 000	1.72	.0022	.0031	.0021	.0039
10 000	1.76	.0000	.0085	.0042	.0080
15 000	1.80	.0000	.0148	.0088	.0125
20 000	1.83	.0000	.0188	.0130	.0157
25 000	1.87	.0006	.0261	.0174	.0210
30 000	1.91	.0058	.0359	.0223	.0257
35 000	1.94	.0132	.0400	.0270	.0300
40 000	1.98	.0206	.0526	.0318	.0342
45 000	2.02	.0284	.0551	.0368	.0392
50 000	2.06	.0296	.0600	.0420	.0443
55 000	2.12	.0317	.0660	.0478	.0500
58 100					
56 000	2.32	.0339	.0769	.0515	.0532
52 000	2.40				
50 500	2.47				
49 600	2.52				

T-Beam No. 71.

1 000	1.78	.0000	.0000	.0000	.0000
5 000	1.80	.0025	.0025	.0033	.0033
10 000	1.83	.0059	.0067	.0088	.0078
15 000	1.87	.0132	.0125	.0131	.0127
20 000	1.92	.0150	.0210	.0188	.0180
25 000	1.96	.0150	.0274	.0235	.0239
30 000	2.01	.0177	.0319	.0310	.0300
35 000	2.08	.0245	.0429	.0381	.0376
40 000	2.16	.0310	.0517	.0459	.0449
42 000	2.28	.0449	.0554	.0480	.0489
31 000		.0415	.0465	.0413	.0408

Original Data, continued.

T—Beam No. 75.

1 000	1.72	.0000	.0000	.0000	.0000
5 000	1.74	.0045	.0024	.0036	.0036
10 000	1.76	.0078	.0077	.0083	.0080
15 000	1.80	.0081	.0121	.0135	.0130
20 000	1.83	.0167	.0185	.0188	.0181
25 000	1.87	.0233	.0270	.0238	.0236
30 000	1.91	.0303	.0357	.0300	.0309
35 000	1.96	.0382	.0437	.0362	.0351
40 000	2.01	.0491	.0512	.0420	.0403
45 000	2.07	.0580	.0607	.0481	.0463
49 200	2.19	.0635	.0644	.0500	.0488
42 000	2.26	.0630	.0640	.0494	.0465
40 000	2.30				
39 400	2.36				
39 000	2.42				

T—Beam No. 76.

500	1.52	.0000	.0000	.0000	.0000
5 000	1.54	.0020	.0035	.0030	.0025
10 000	1.56	.0121	.0152	.0077	.0060
15 000	1.58	.0162	.0194	.0125	.0075
20 000	1.60	.0227	.0237	.0173	.0110
25 000	1.65	.0330	.0306	.0230	.0150
30 000	1.70	.0390	.0385	.0283	.0166
35 000	1.75	.0484	.0449	.0342	.0222
40 000	1.80	.0544	.0515	.0403	.0282
45 000	1.88	.0607	.0580	.0486	.0350
50 000	2.00	.0700	.0660	.0553	.0407
51 200	2.10	.0719	.0700	.0575	.0424
40 000	2.22	.0595	.0507	.0420	.0382
30 000	2.28	.0547	.0482	.0401	.0250
25 000	2.38	.0482	.0480	.0398	.0182

Original Data, continued.

T-Beam No. 86.

500	1.72	.0000	.0000	.0000	.0000
3 000	1.73	.0023	.0000	.0017	.0005
6 000	1.74	.0037	.0000	.0041	.0030
9 000	1.76	.0053	.0000	.0079	.0046
12 000	1.78	.0082	.0000 .3200	.0109	.0076
-15 000	1.80	.0153	.3200	.0139	.0103
-18 000	1.82	.0186	.3207	.0170	.0126
21 000	1.84	.0193	.3207 .2000	.0201	.0157
24 000	1.89	.0244	.2000	.0238	.0190
26 200	Failed.				

T-Beam No. 87.

500	1.89	.0000	.0000	.0000	.0000
3 000	1.90	.0070	.0050	.0083	.0103
6 000	1.91	.0070	.0001	.0100	.0220
9 000	1.94	.0045 .3300	.4990	.0122	.0220
12 000	1.94	.3340	.4990	.0150	.0200
15 000	1.97	.3385	.4952	.0179	.0178
17 600	Failed.				

Computed Data

Load	Deflection inches	Unit Deformation in Steel	Unit Deformation in Upper Fiber	K
		T-Beam No. 66.		
1 200	.00	.00000	.00000	.00
5 000	.01	.00003	.00004	.58
10 000	.04	.00008	.00016	.67
15 000	.08	.00028	.00022	.50
20 000	.13	.00025	.00050	.60
25 000	.18	.00038	.00034	.48
30 000	.24	.00047	.00060	.57 ✓
34 000				
19 300		.00043	.00067	.60
15 000		.00040	.00057	.60
		T-Beam No. 55.		
400	.00	.00000	.00000	.00
5 000	.03	.00003	.00008	.73
10 000	.07	.00004	.00020	.82
15 000	.12	.00002	.00040	.98
20 000	.18	.00003	.00053	.95
25 000	.27	.00017	.00061	.78
30 000	.41	.00033	.00071	.68 ✓
31 300	.54	.00037	.00084	.68
22 000	.64	.00033	.00092	.73
15 000	.72	.00029	.00085	.75
12 000	.83	.00027	.00050	.77
		T-Beam No. 60.		
1 000	.00	.00000	.00000	.00
5 000	.03	.00002	.00007	.79
10 000	.06	.00011	.00017	.60
15 000	.10	.00021	.00027	.58
20 000	.16	.00037	.00037	.50
25 000	.24	.00047	.00050	.52
26 100	.35	.00048	.00053	.54
20 000	.42	.00047	.00045	.50
14 700		.00034	.00037	.52

T-Beam No. 75.

1 000	.00	.00000	.00000	.00
5 000	.02	.00004	.00007	.61
10 000	.04	.00009	.00016	.65
15 000	.08	.00009	.00026	.75
20 000	.11	.00021	.00040	.62
25 000	.14	.00032	.00042	.56
30 000	.19	.00042	.00054	.56
35 000	.24	.00055	.00063	.53
40 000	.29	~~.00072~~ 70	~~.00080~~ 70	.51 ✓
45 000	.35	.00085	.00078	.48
49 200	.47	.00093	.00080	.46 ✓
42 000	.56	.00093	.00077	.45
40 000	.58			
39 400	.64			
39 000	.70			

T-Beam No. 65.

600	.00	.00000	.00000	.00
5 000	.03	.00000	.00005	.99
10 000	.06	.00000	.00014	1.00
15 000	.09	.00000	.00027	1.00
20 000	.13	.00000	.00040	1.18
25 000	.17	.00004	.00046	.90
30 000	.22	.00029	.00510	.64
35 000	.28	.00030	.00065	.68 ✓
40 000	.33	.00042	.00074	.64 ✓
43 800	.47	.00057	.00054	.50
30 000	.57	.00060	.00050	.47
28 000		.00060	.00043	.45

T-Beam No. 70.

1 500	.00	.00000	.00000	.00
5 000	.02	.00002	.00006	.70
10 000	.06	.00011	.00011	.50
15 000	.10	.00023	.00015	.41
20 000	.13	.00027	.00023	.45
25 000	.17	.00038	.00030	.44
30 000	.21	.00056	.00035	.41
35 000	.24	.00061	.00043	.42
40 000	.28	.00095	.00056	.35
45 000	.32	.00086	.00056	.40
50 000	.36	.00090	.00070	.45
55 000	.42	.00096	.00077	.45
58 100		Maximum Load.		
56 000	.62	.00120	.00076	.41
52 000	.70			
50 500	.77			
49 600	.86			

T-Beam No. 56.

1 000	.00	.00000	.00000	.00
5 000	.02	.00003	.00006	.70
10 000	.05	.00010	.00013	.59
15 000	.08	.00023	.00045	.66
20 000	.13	.00030	.00033	.52
25 000	.17	.00040	.00037	.48
30 000	.22	.00050	.00054	.52
35 000	.27	.00055	.00067	.56 ✓
40 000	.34	.00060	.00080	.58 ✓
45 000	.47	.00068	.00096	.59
45 700	.55	.00083	.00094	.53
26 000				

T-Beam No. 61.

1 000	.00	.00000	.00000	.00
5 000	.01	.00004	.00007	.68
10 000	.05	.00011	.00017	.60
15 000	.07	.00023	.00025	.54
20 000	.14	.00029	.00039	.57 ✓
25 000	.18	.00044	.00047	.52 ✓
30 000	.27	.00046	.00064	.58 ✓
33 000	.45	.00048	.00074	.61
24 000	.45	.00054	.00055	.52

T-Beam No. 76.

500	.00	.00000	.00000	.00
5 000	.02	.00004	.00004	.60
10 000	.04	.00023	.00007	.24
15 000	.06	.00030	.00013	.30
20 000	.08	.00037	.00020	.35
25 000	.13	.00054	.00020	.28
30 000	.18	.00065	.00029	.30
35 000	.23	.00076	.00038	.34
40 000	.28	.00084	.00049	.37 ✓
45 000	.36	.00077	.00068	.50
50 000	.48	.00103	.00074	.41 ✓
51 200	Maximum Load.			
51 200	.58	.00107	.00077	.42
40 000	.70	.00081	.00067	.45
30 000	.76	.00083	.00047	.38
25 000	.86			

T-Beam No. 50.

500	.00	.00000	.00000	.00
5 000	.02	.00000	.00000	.00
10 000	.04	.00000	.00020	1.30
15 000	.07	.00005	.00029	.85
20 000	.12	.00015	.00037	.70
25 000	.16	.00027	.00044	.63
30 000	.20	.00029	.00060	.66
35 000	.26	.00042	.00070	.62
40 000	.32	.00050	.00085	.62
45 000	.40	.00057	.00097	.62
47 000	.46	.00066	.00095	.59
40 000	.72	.00073	.00140	.67
35 000	.84	.00073	.00131	.66

T-Beam No. 86.

500	.00	.00000	.00000	.00
5 000	.01	.00004	.00003	.30
6 000	.02	.00004	.00006	.60
9 000	.04	.00006	.00012	.68
12 000	.06	.00009	.00017	.66
15 000	.08	.00023	.00017	.45
18 000	.10	.00027	.00024	.49
21 000	.12	.00025	.00032	.57
24 000	.17	.00033	.00037	.55
26 200	Failure.			

T-Beam No. 87.

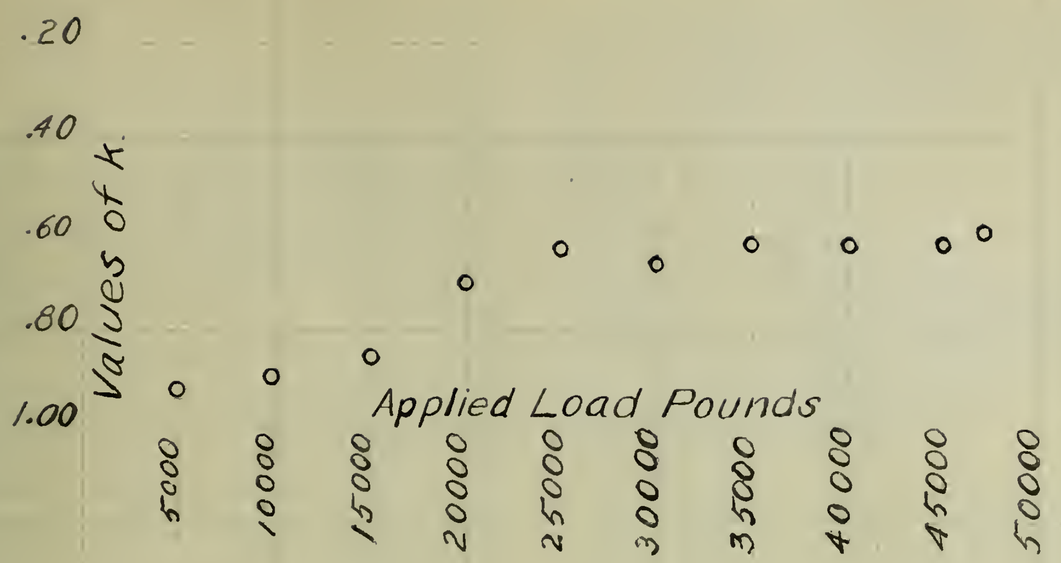
500	.00
3 000	.01
6 000	.02
9 000	.03
12 000	.05
15 000	.08
17 600	Failure.

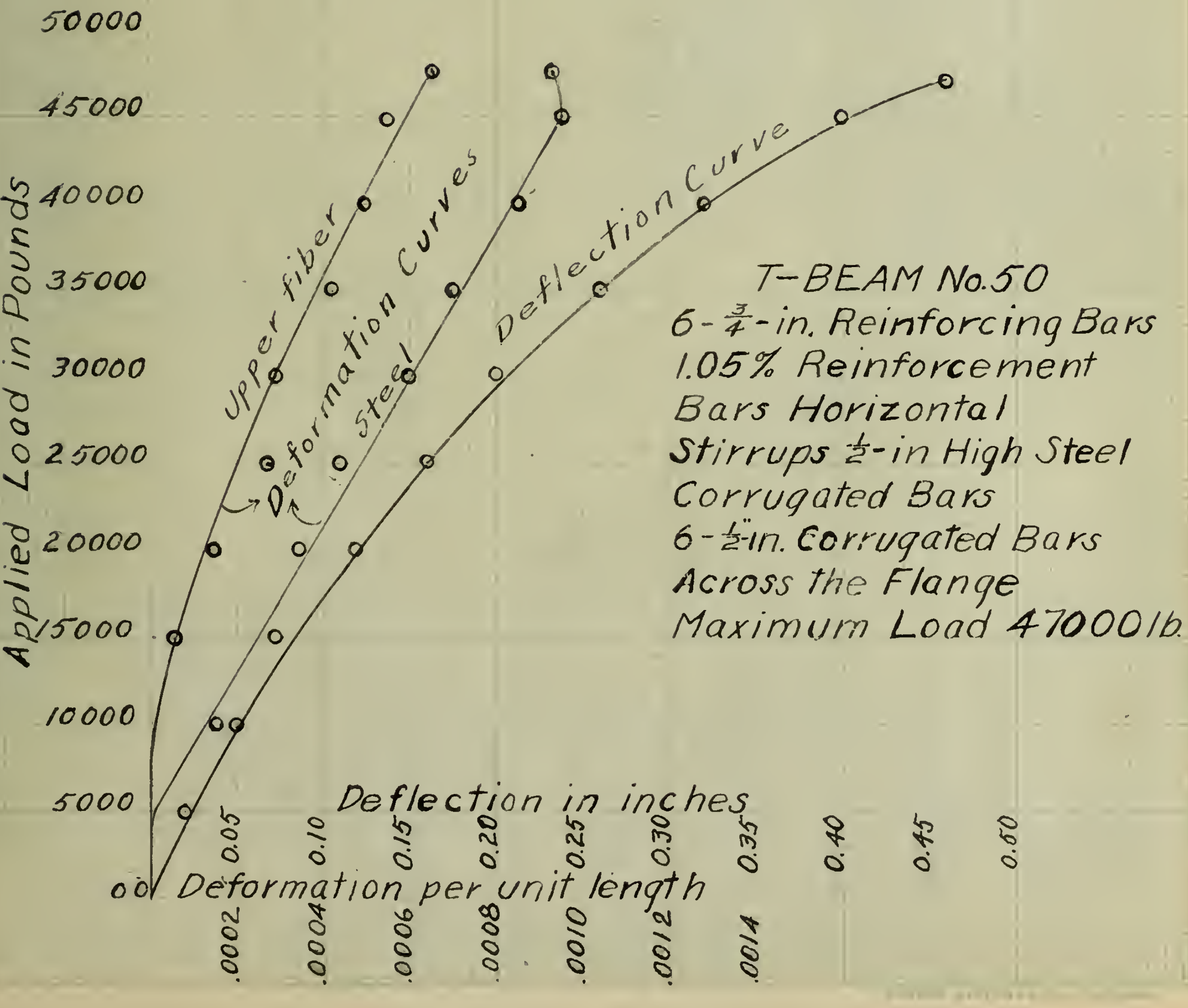
T-Beam No. 51.

1 000	.00	.00000	.00000	.00
5 000	.03	.00005	.00006	.58
10 000	.06	.00011	.00015	.60
15 000	.10	.00024	.00024	.50
20 000	.14	.00041	.00031	.44
25 000	.21	.00052	.00040	.45
29 000	.30	.00057	.00053	.50
25 000	.38	.00057	.00049	.48
20 000	.49	.00057	.00043	.44

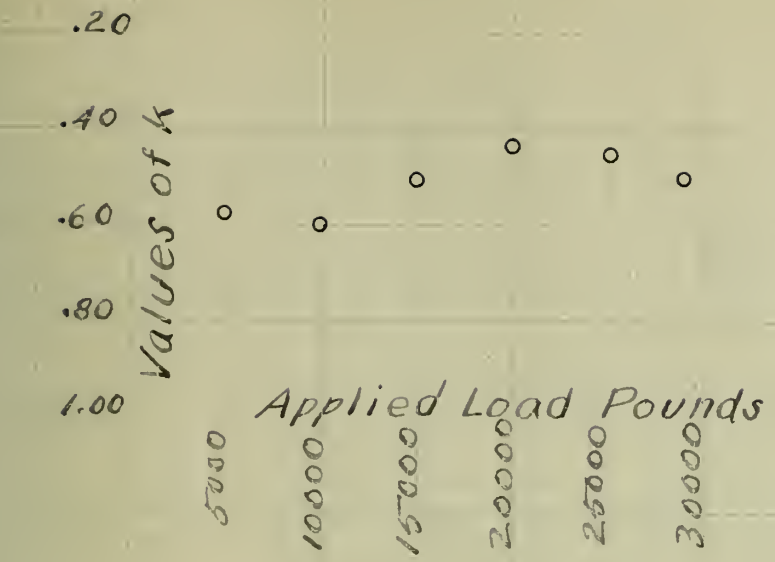
T-Beam No. 71.

1 000	.00	.00000	.00000	.00
5 000	.02	.00003	.00007	.71
10 000	.05	.00007	.00015	.70
15 000	.09	.00016	.00023	.60
20 000	.14	.00021	.00034	.63
25 000	.18	.00023	.00046	.66
30 000	.23	.00024	.00060	.71
35 000	.30	.00037	.00073	.66
40 000	.38	.00063	.00081	.58
42 000	.50	.00063	.00087	.59
31 000		.00057	.00074	.58

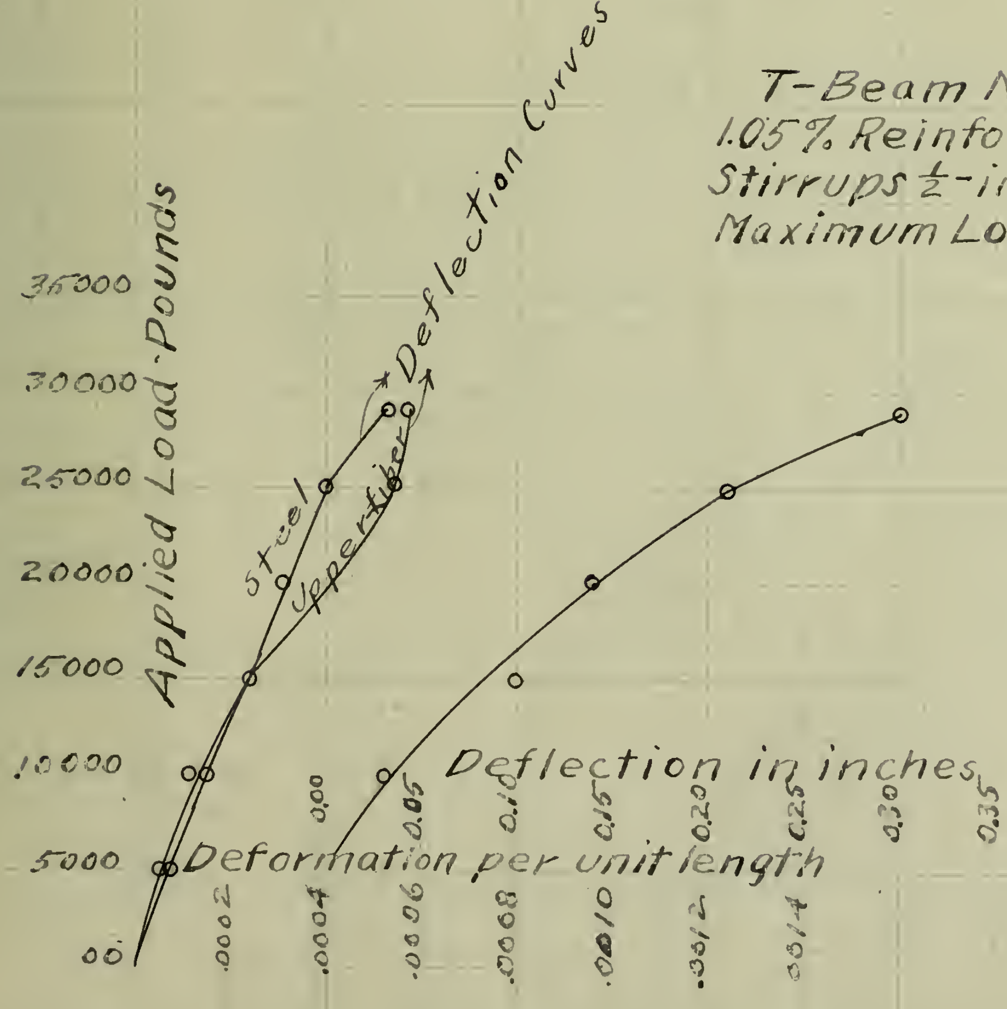


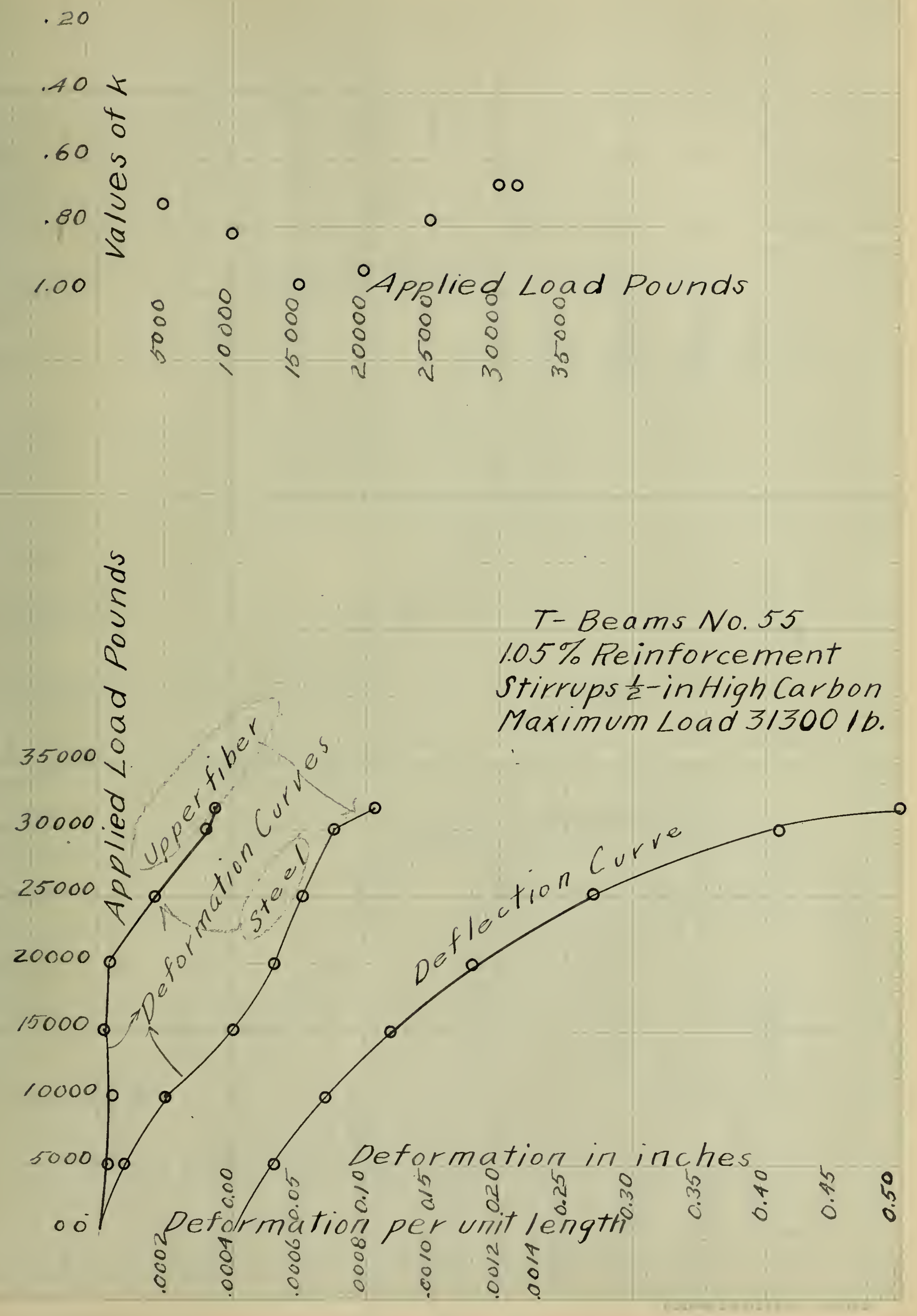


T-BEAM No.50
6-$\frac{3}{4}$-in. Reinforcing Bars
1.05% Reinforcement
Bars Horizontal
Stirrups $\frac{1}{2}$-in High Steel
Corrugated Bars
6-$\frac{1}{2}$-in. Corrugated Bars
Across the Flange
Maximum Load 47000 lb.

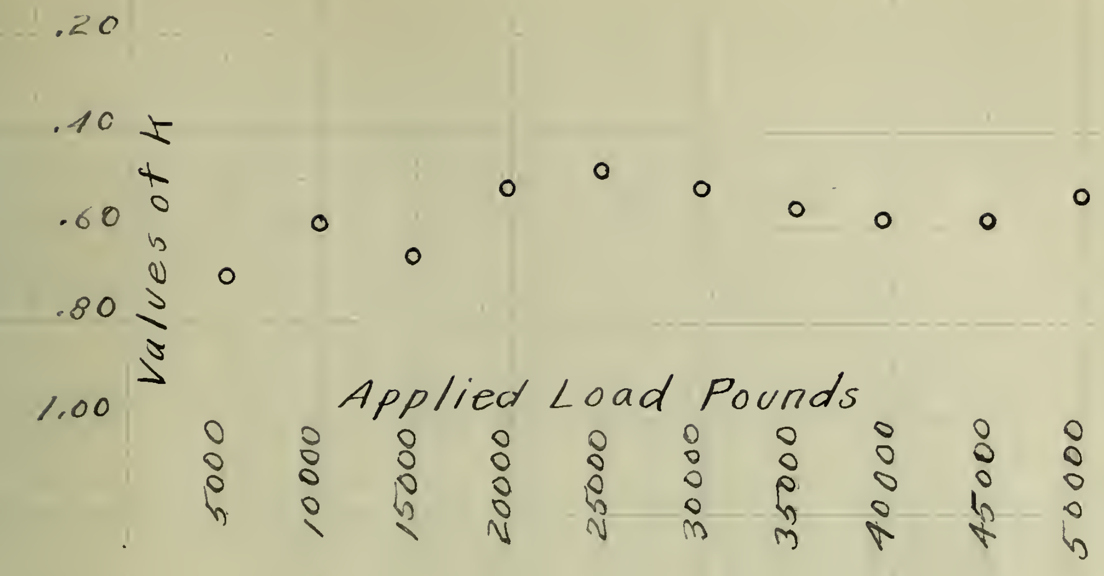


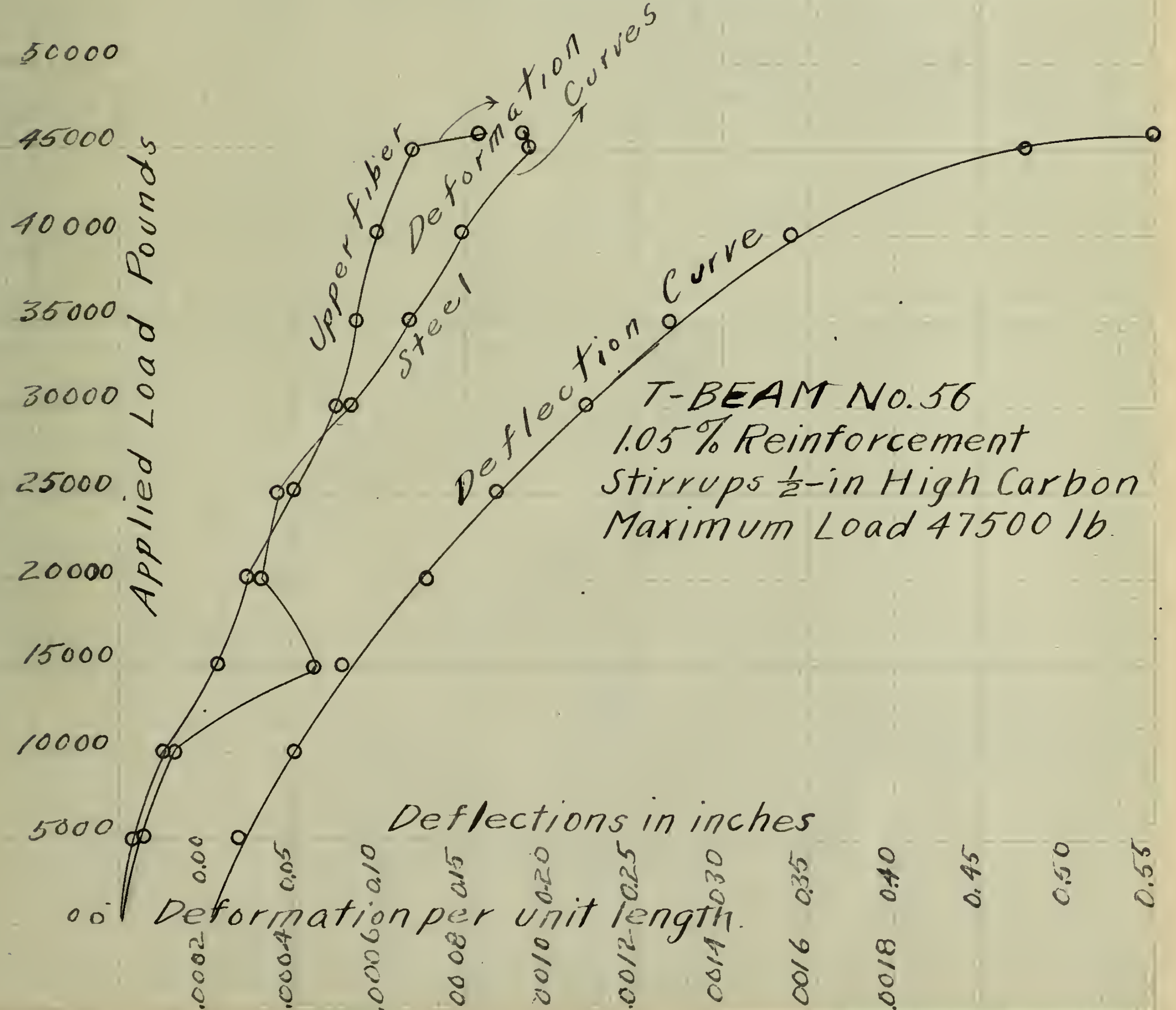
T-Beam No. 51
1.05% Reinforcement
Stirrups ½-in High Steel
Maximum Load 29000 lb

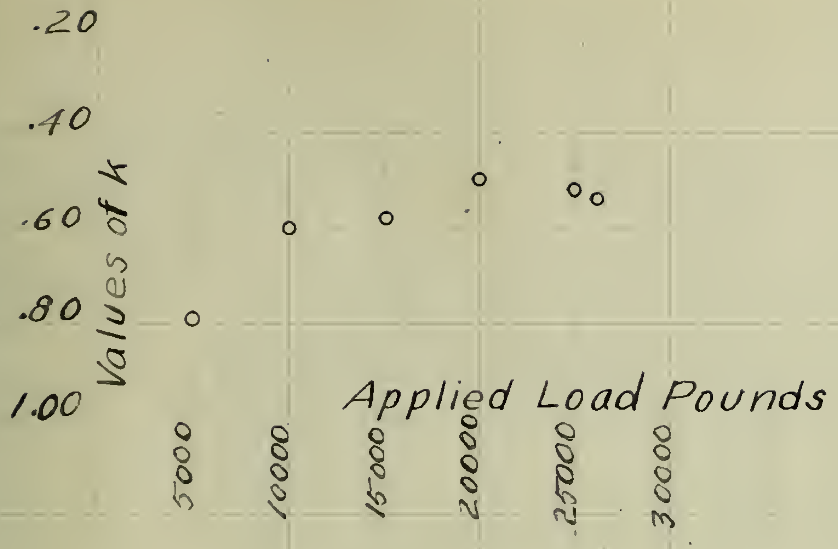




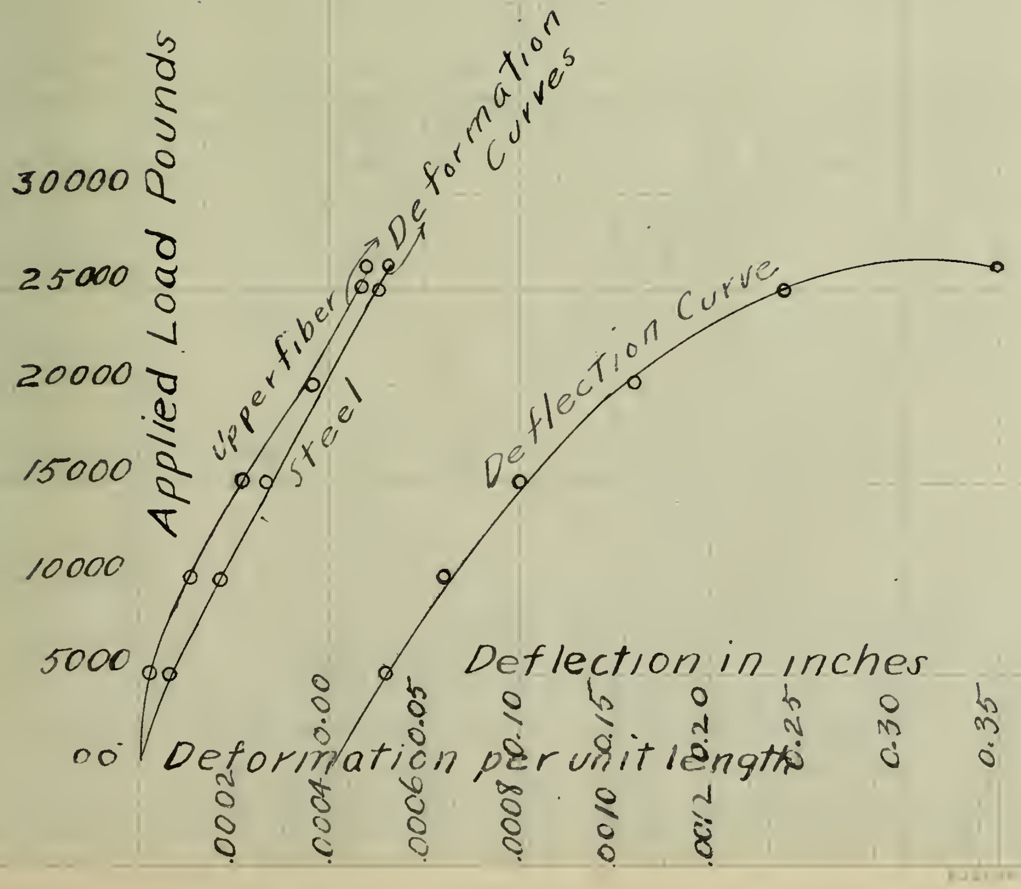
T- Beams No. 55
1.05% Reinforcement
Stirrups ½-in High Carbon
Maximum Load 31300 lb.

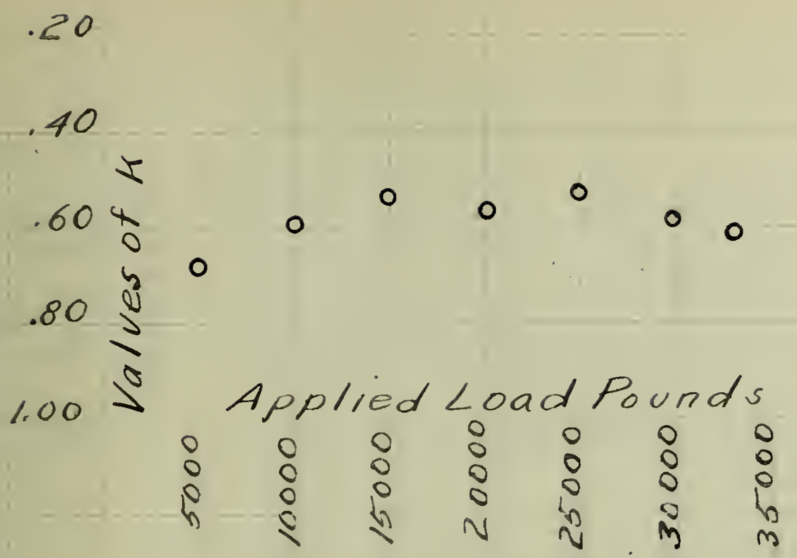



T-BEAM No.56
1.05% Reinforcement
Stirrups ½-in High Carbon
Maximum Load 47500 lb.

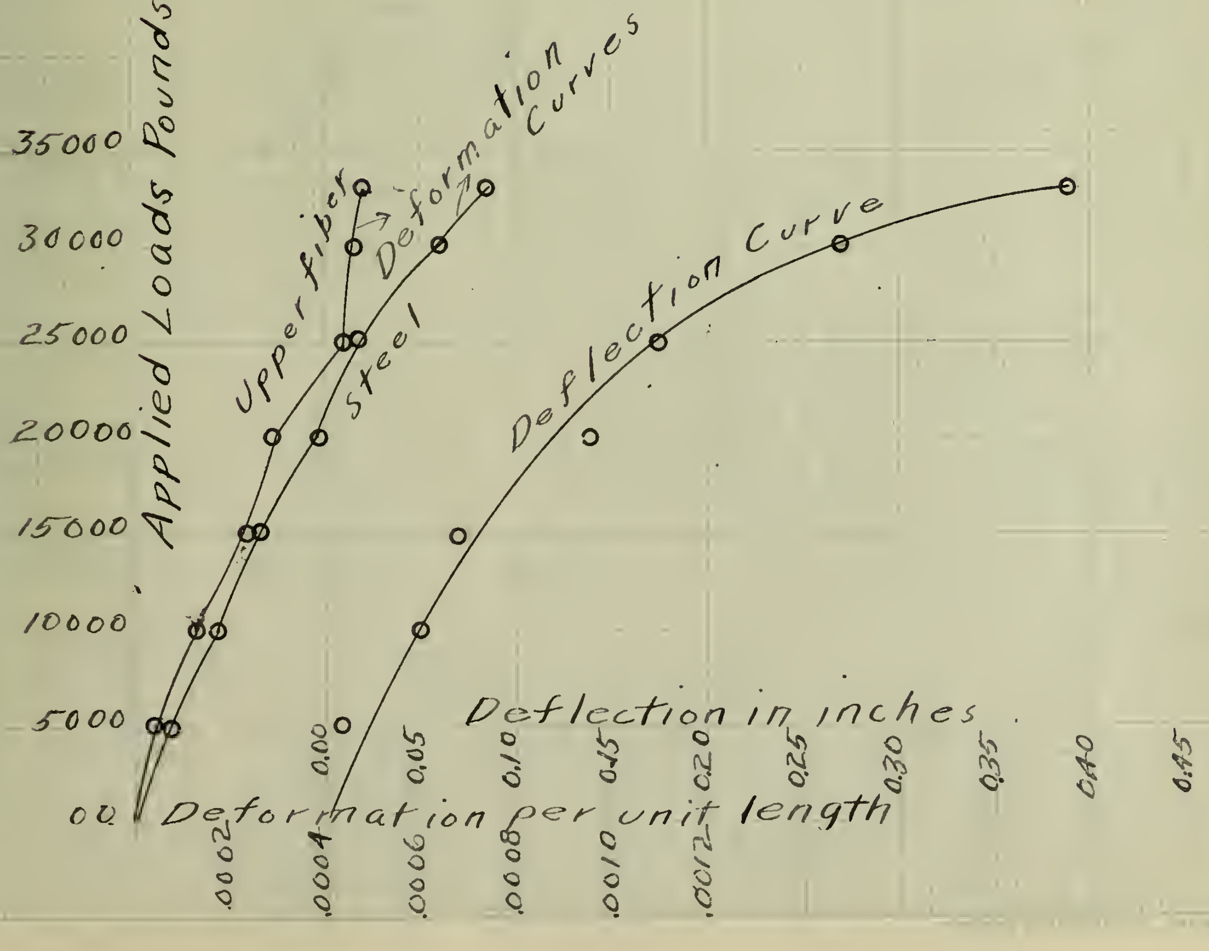


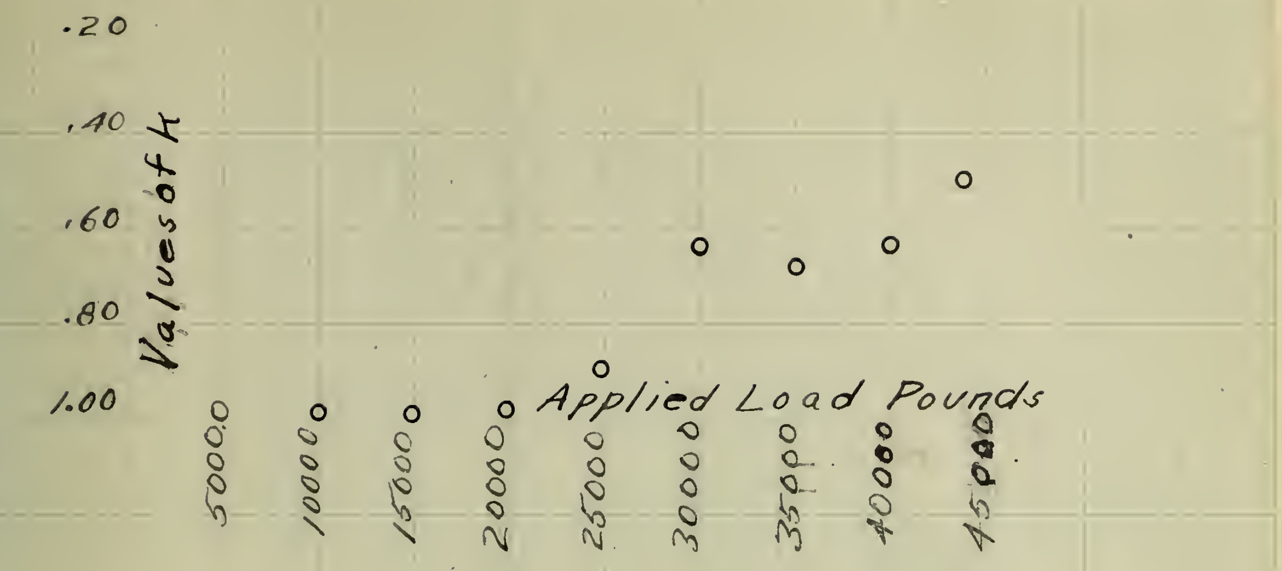
T-Beam No. 60
1.05% Reinforcement
Stirrups ¼-in. High Steel
Maximum Load 26100 lb.

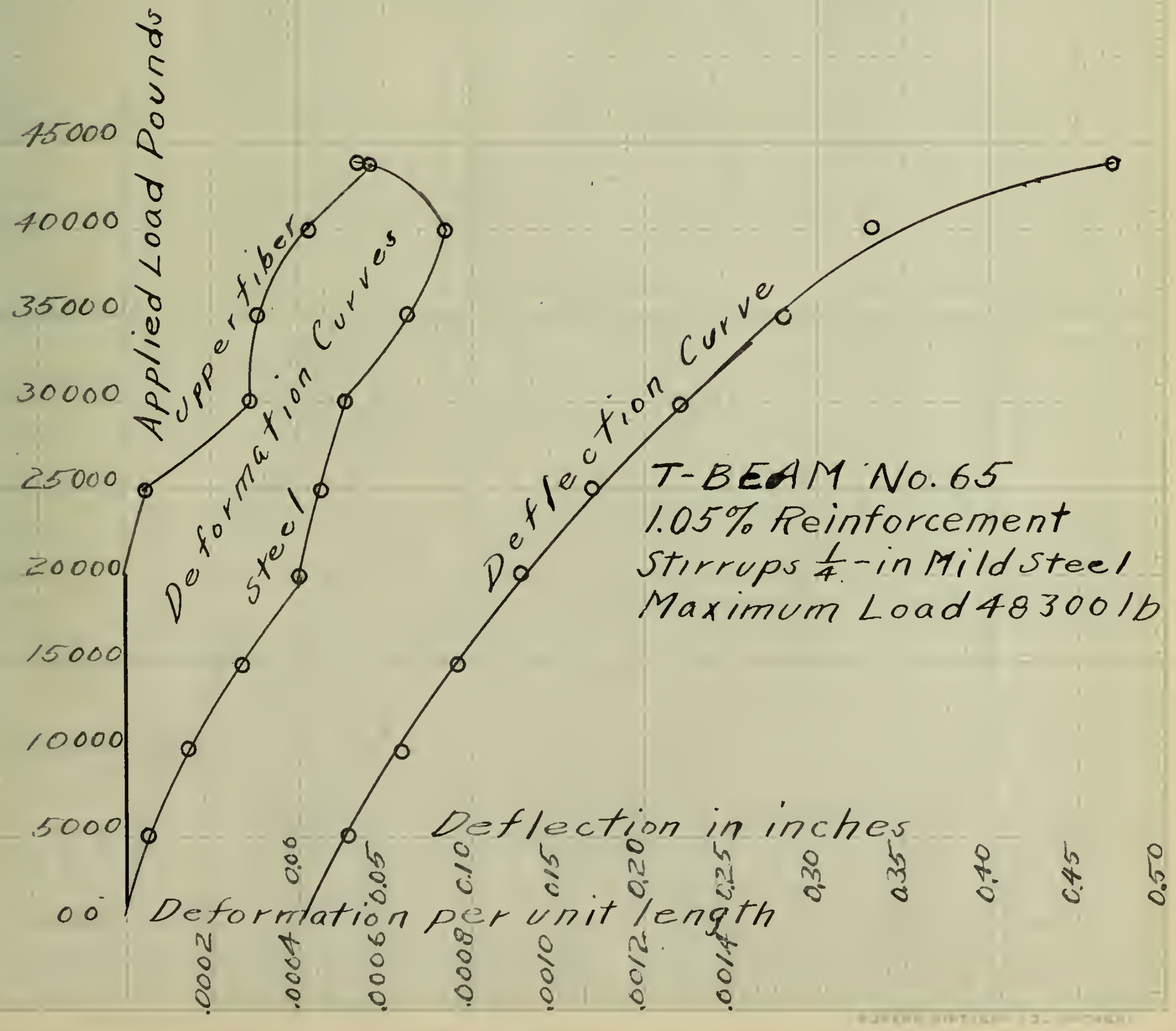




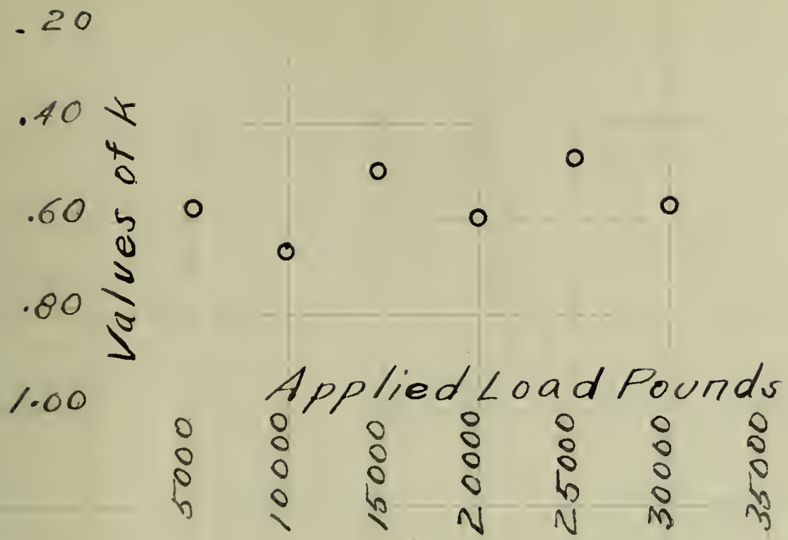
T-BEAM No. 61
1.05% Reinforcement
Stirrups ¼-in High Steel
Maximum Load 33000 lb.

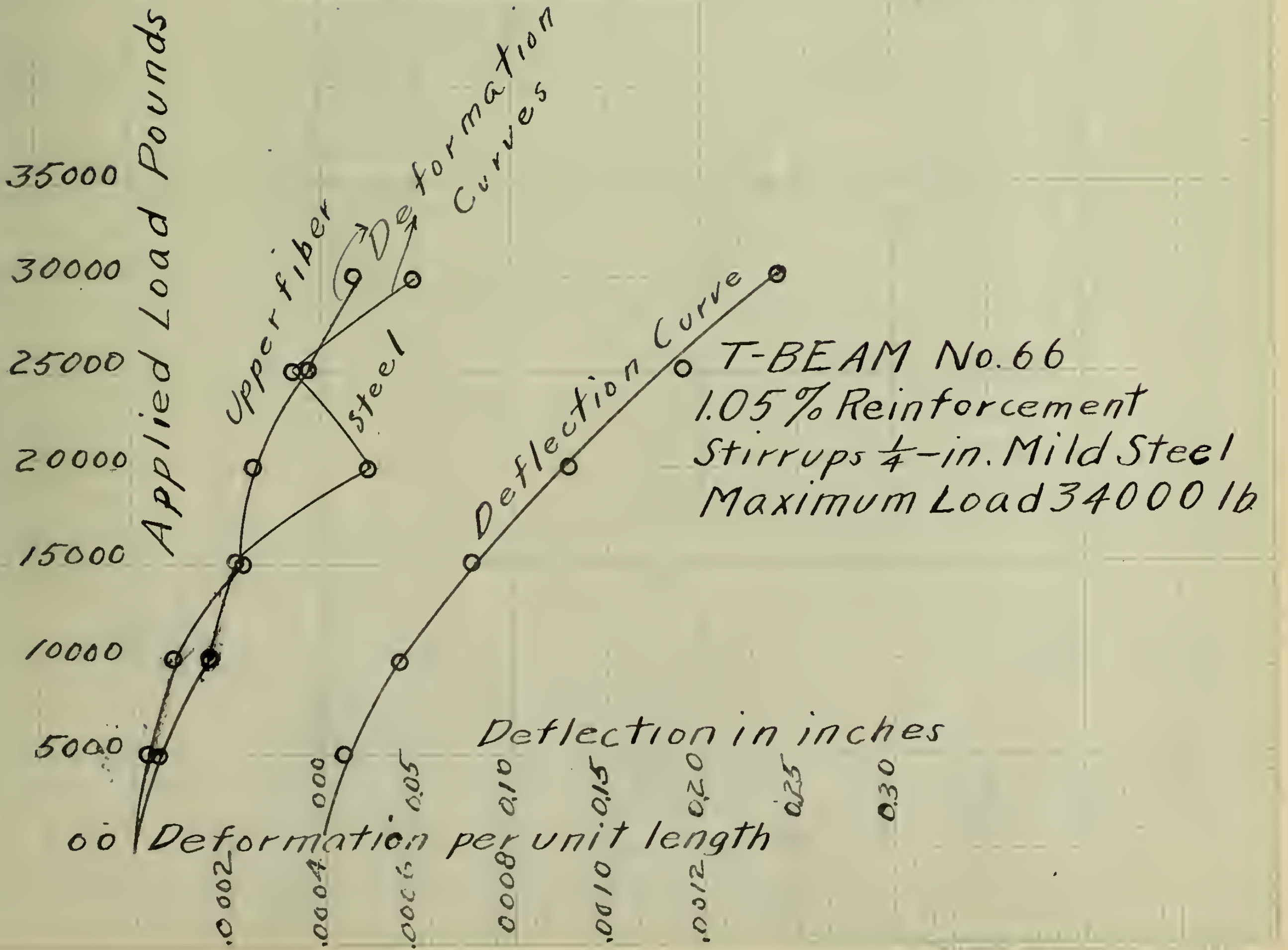


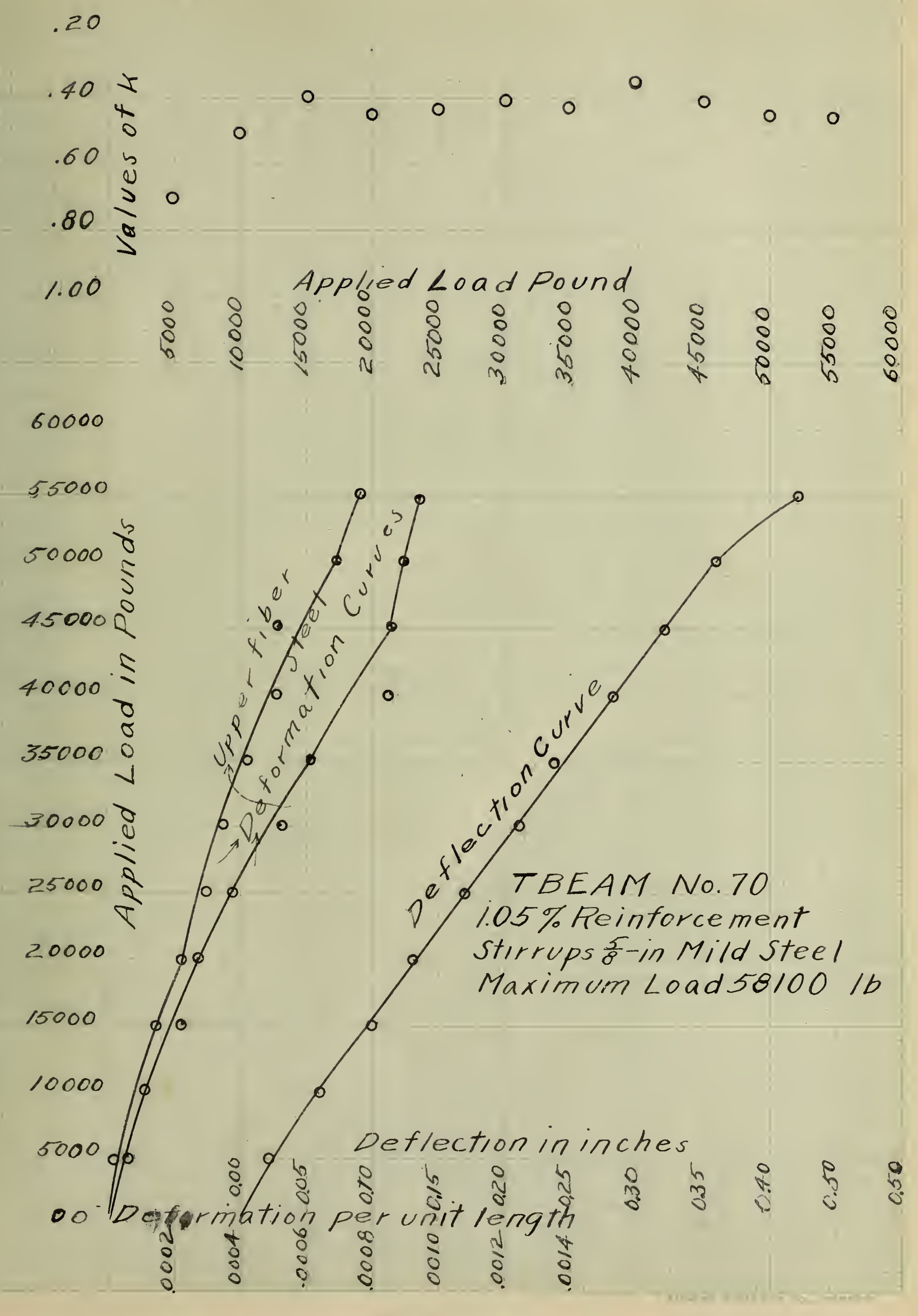


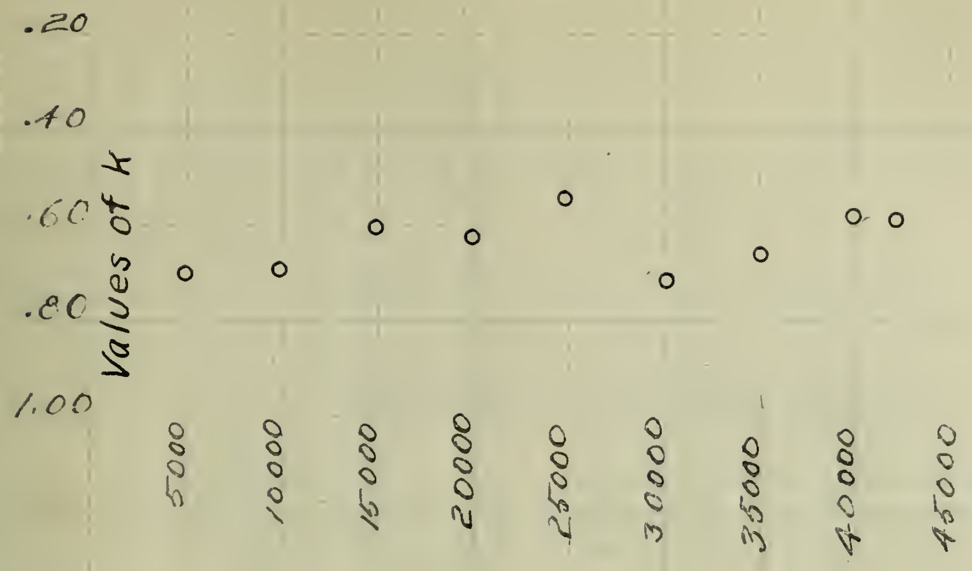


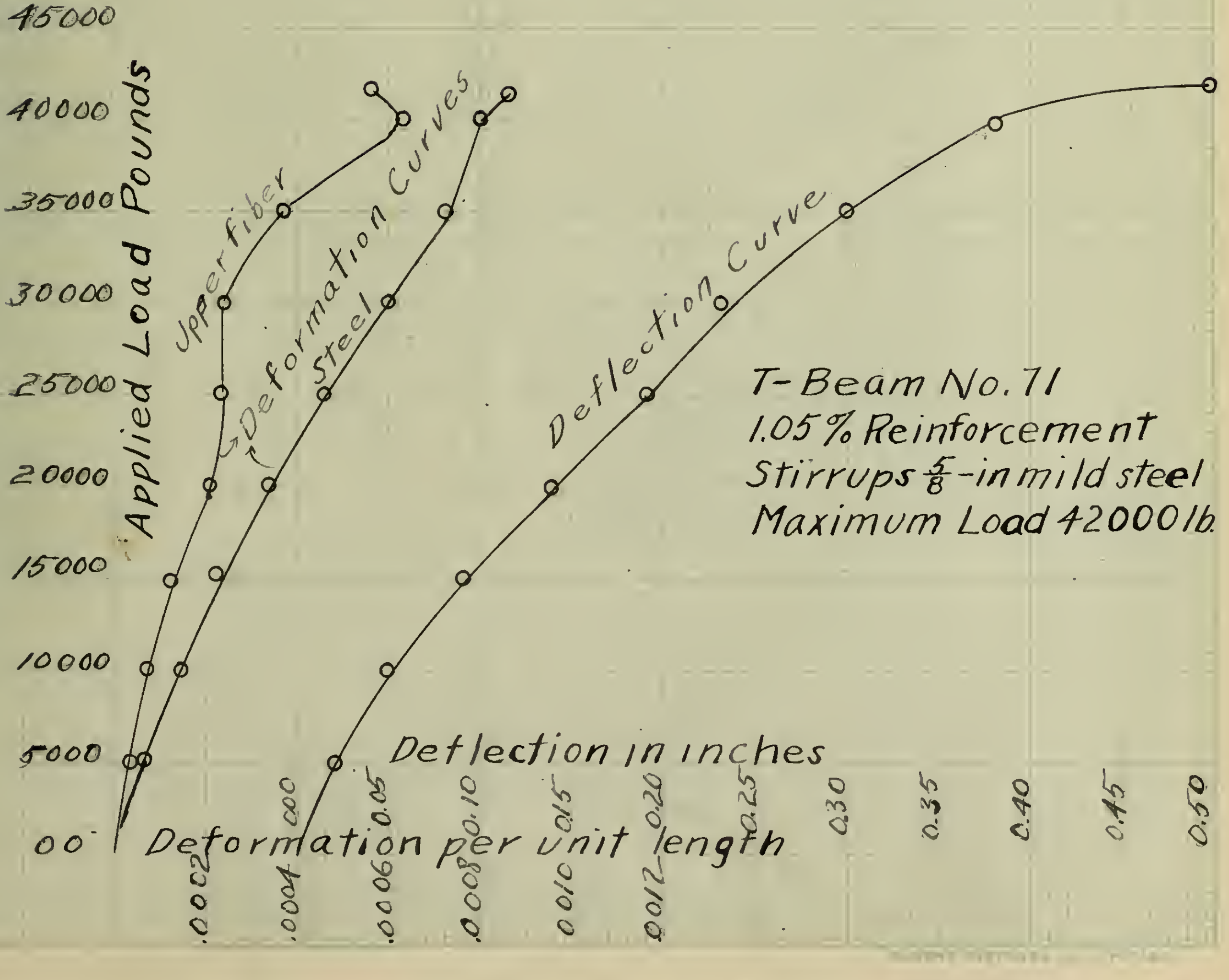
T-BEAM No. 65
1.05% Reinforcement
Stirrups $\frac{1}{4}$-in Mild Steel
Maximum Load 48300 lb

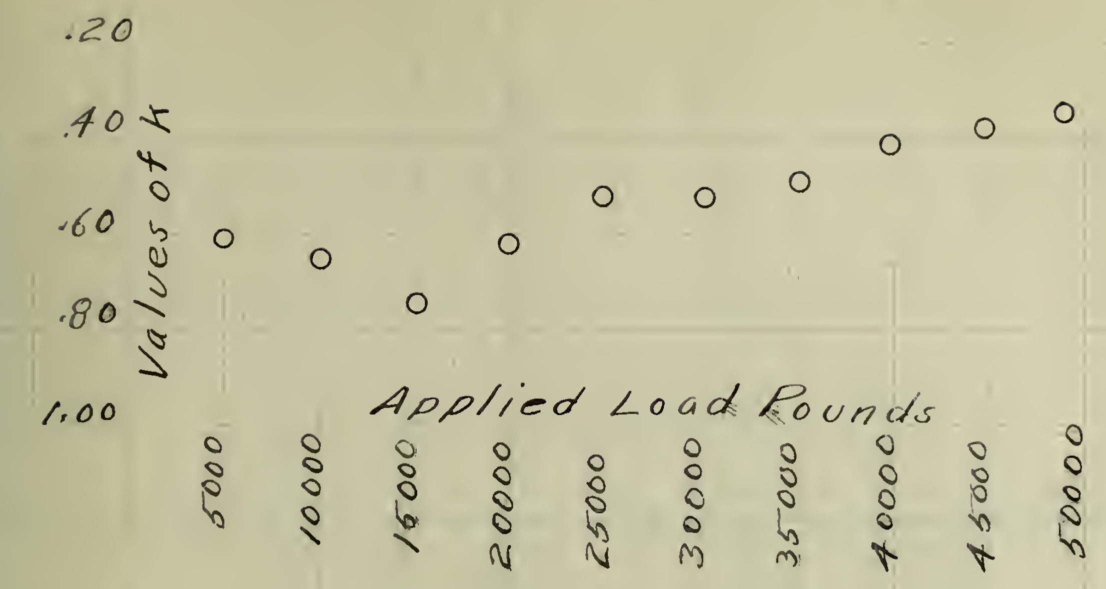


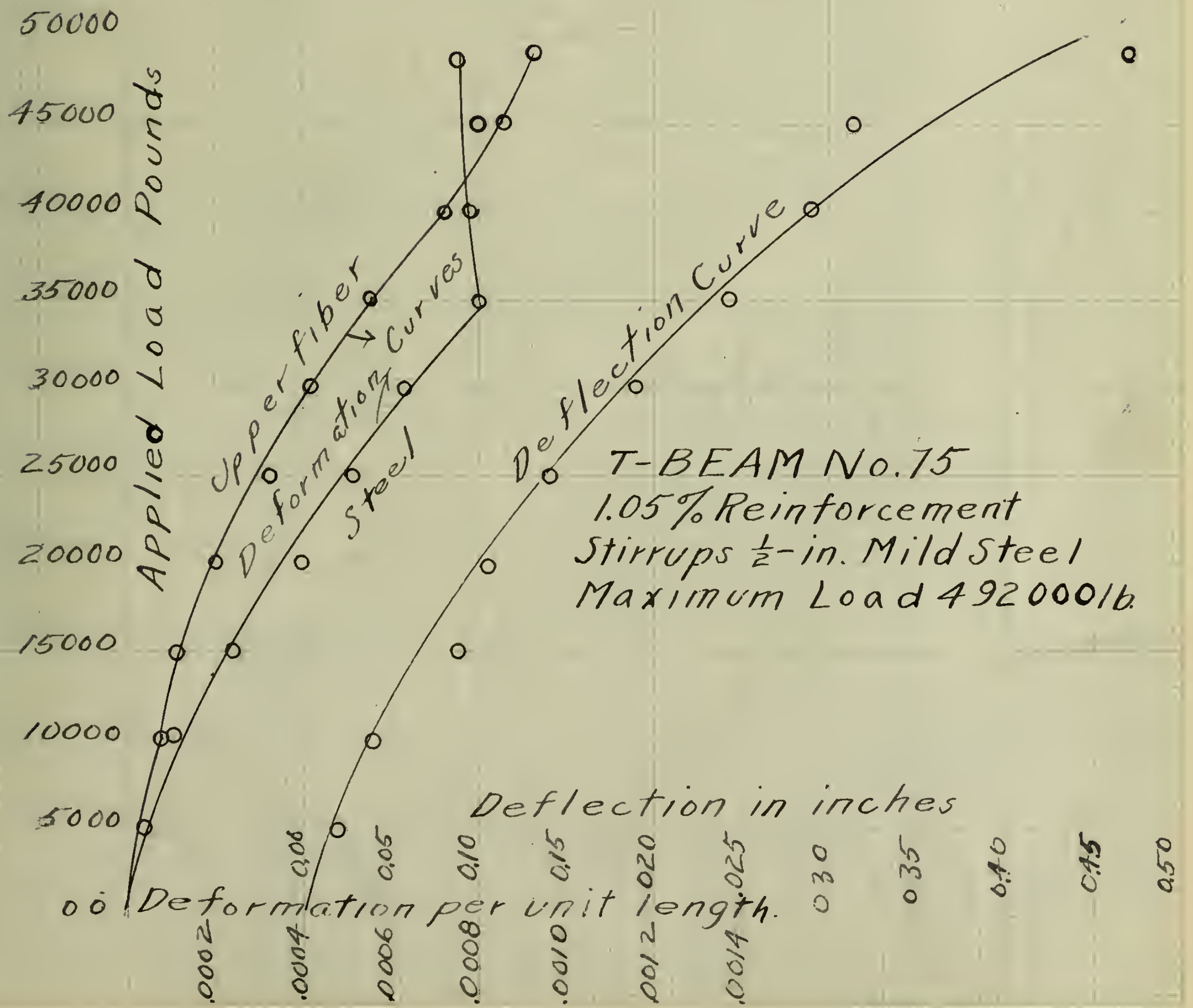

T-BEAM No. 66
1.05% Reinforcement
Stirrups $\frac{1}{4}$-in. Mild Steel
Maximum Load 34000 lb


TBEAM No.70
1.05% Reinforcement
Stirrups $\frac{5}{8}$-in Mild Steel
Maximum Load 58100 lb

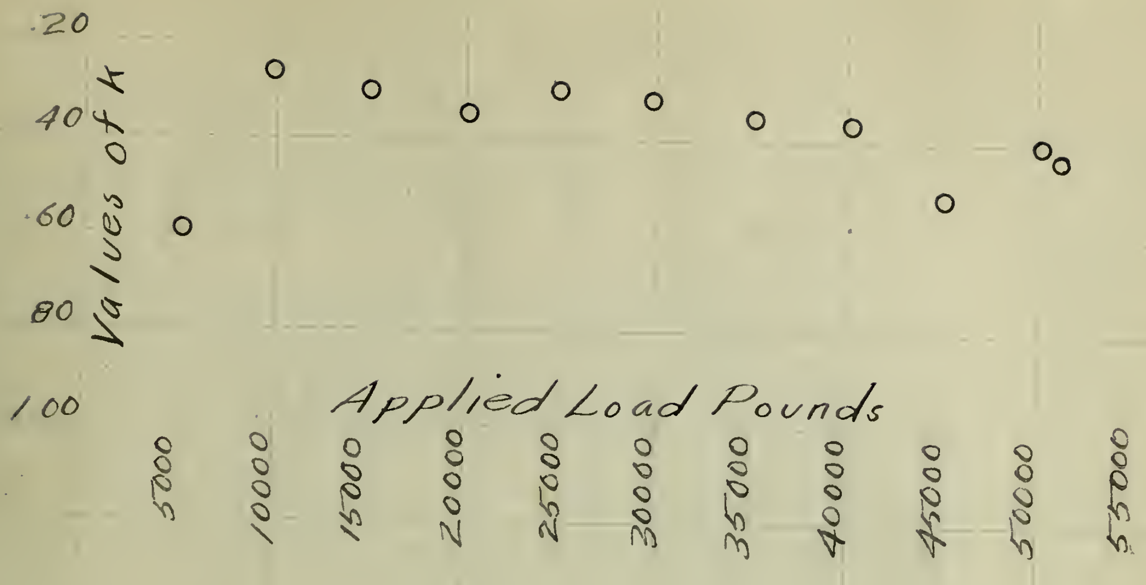


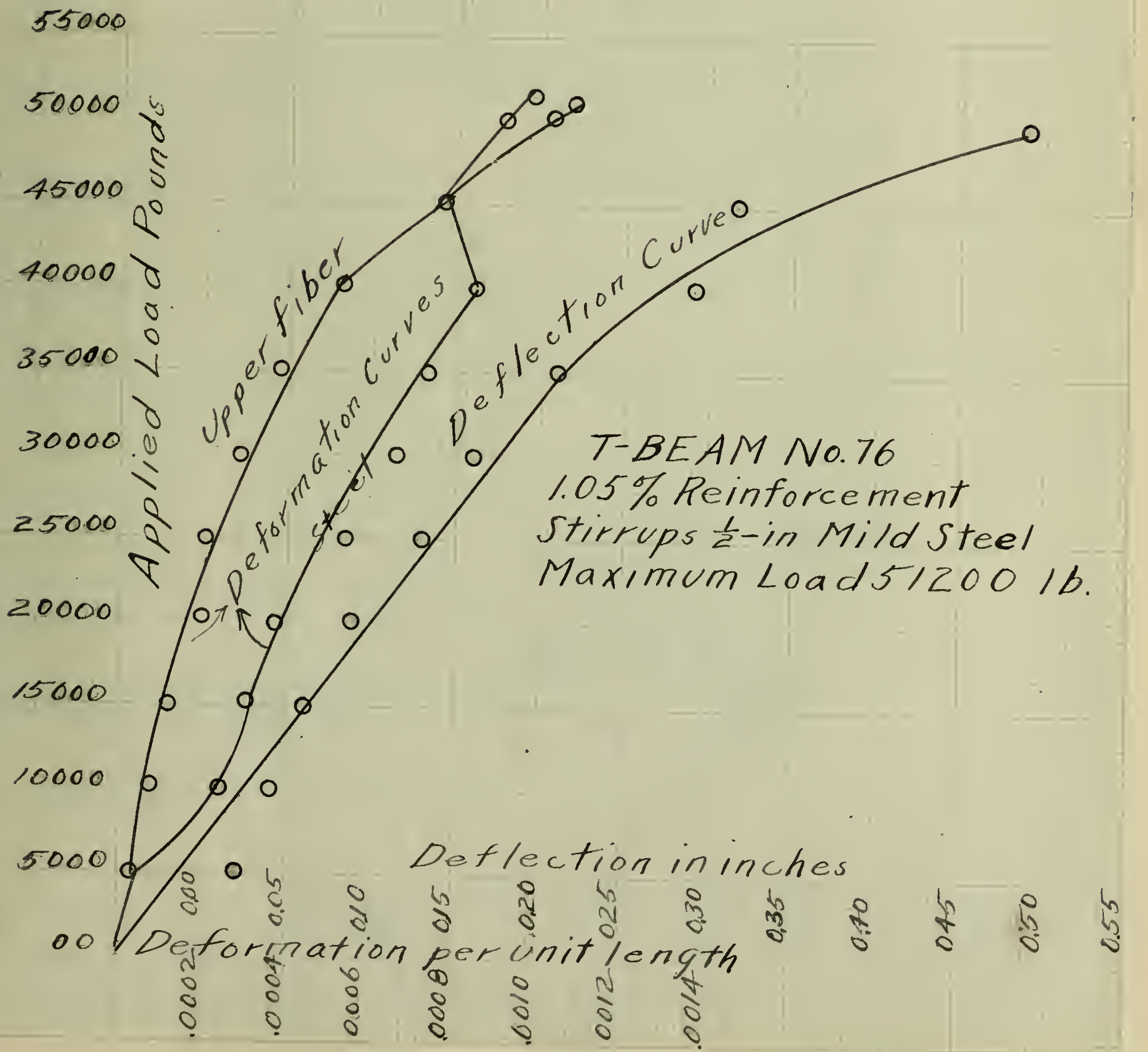

T-Beam No. 71
1.05% Reinforcement
Stirrups $\frac{5}{8}$-in mild steel
Maximum Load 42000 lb.

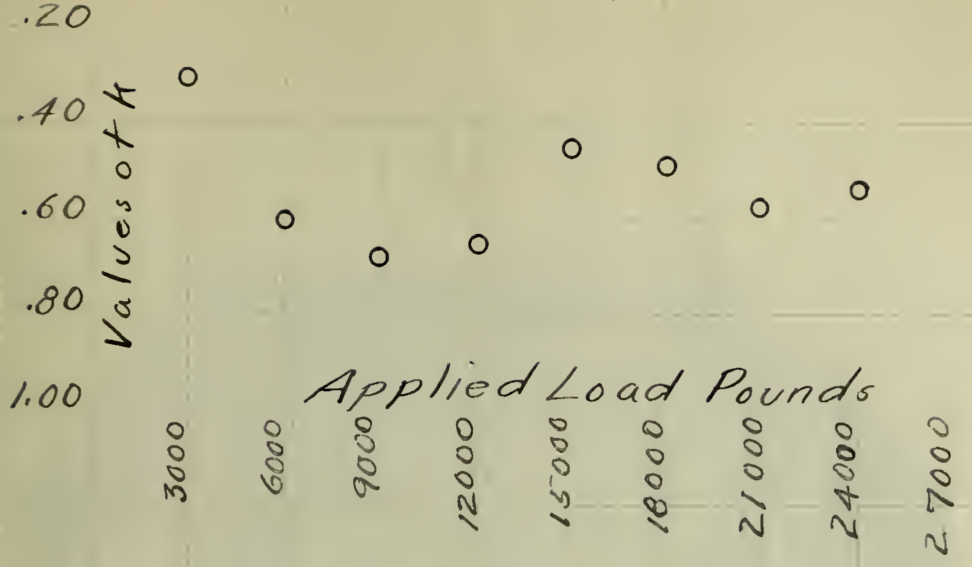


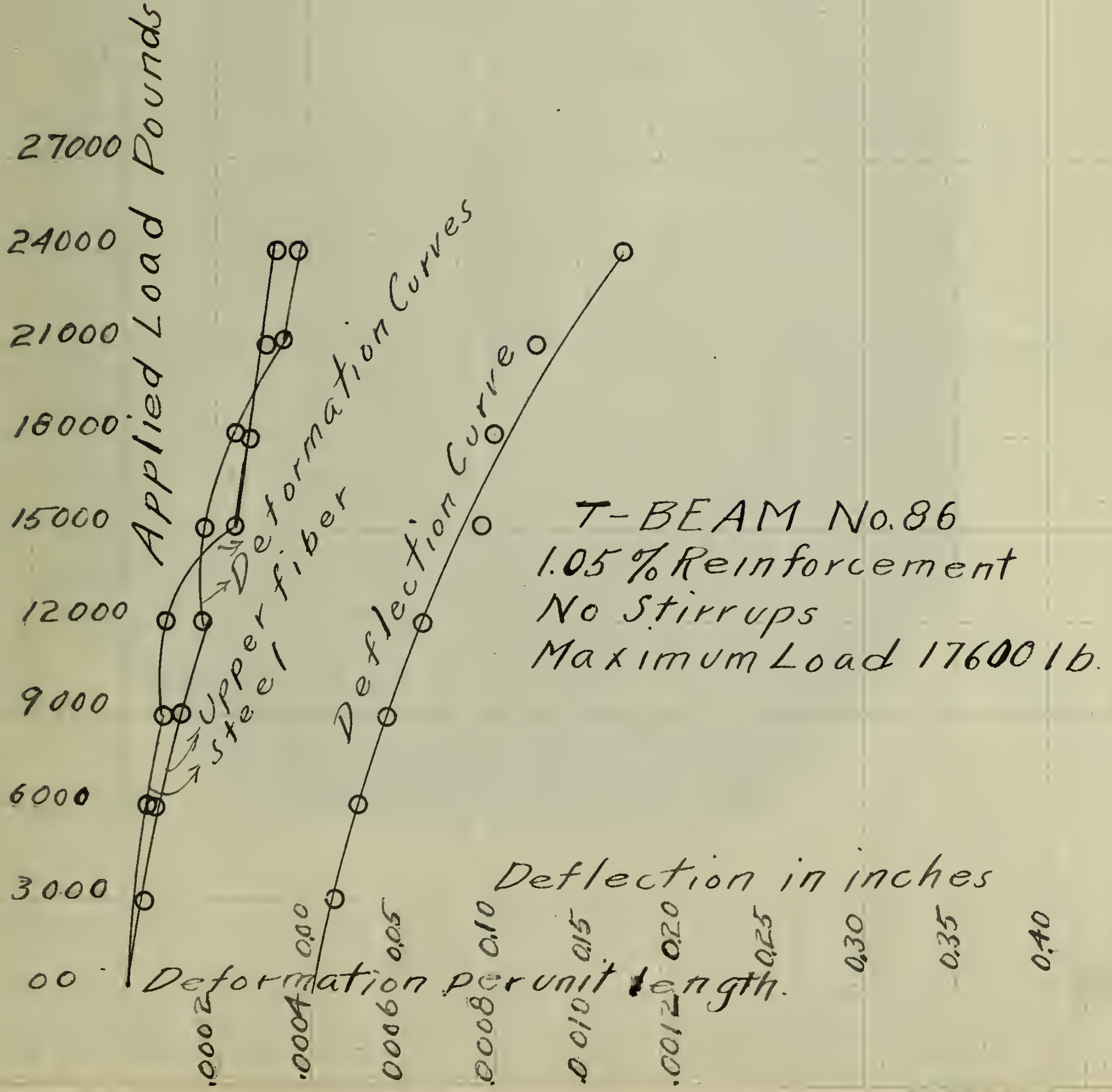


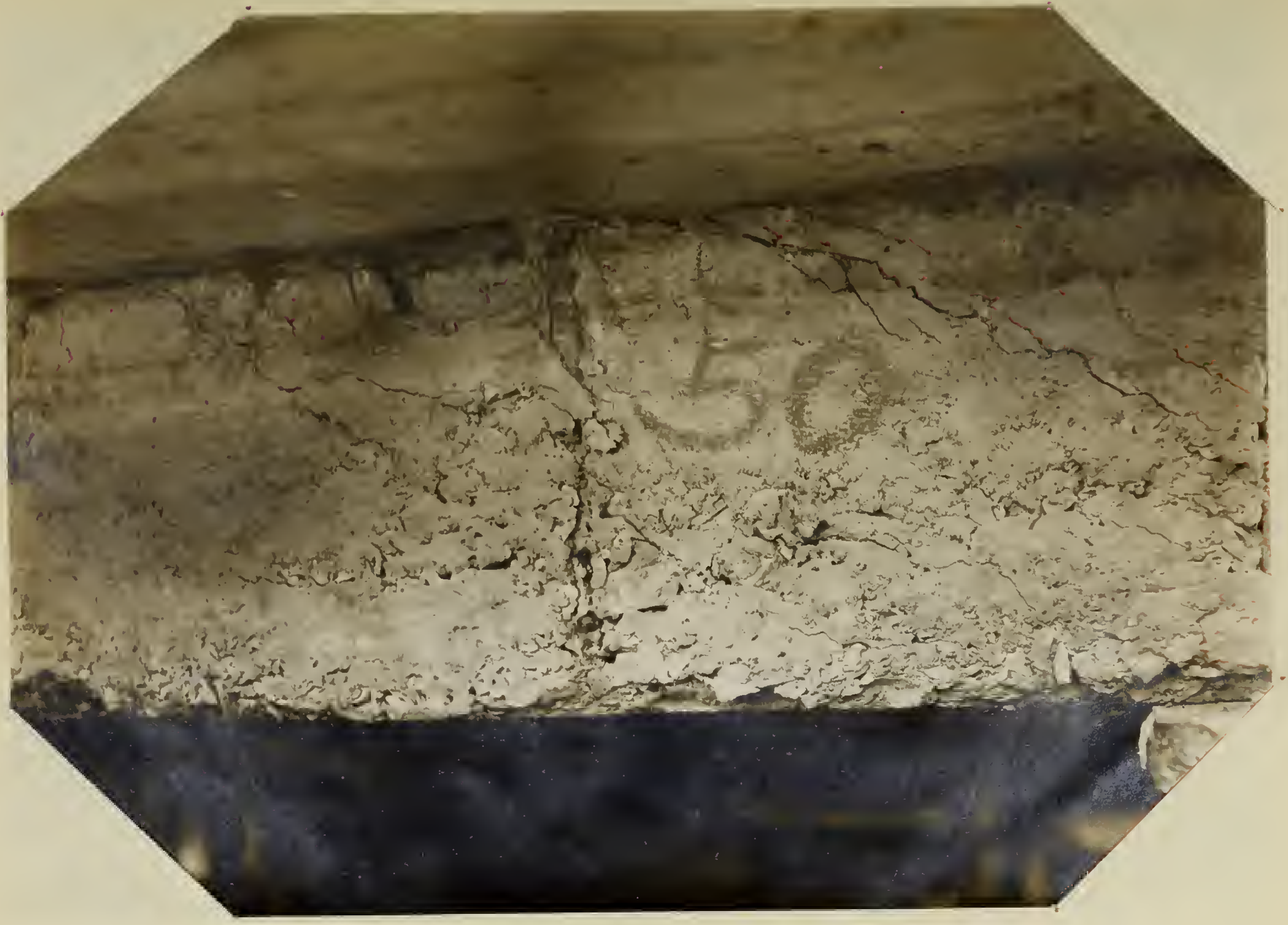
T-BEAM No. 75
1.05% Reinforcement
Stirrups ½-in. Mild Steel
Maximum Load 49200 lb.



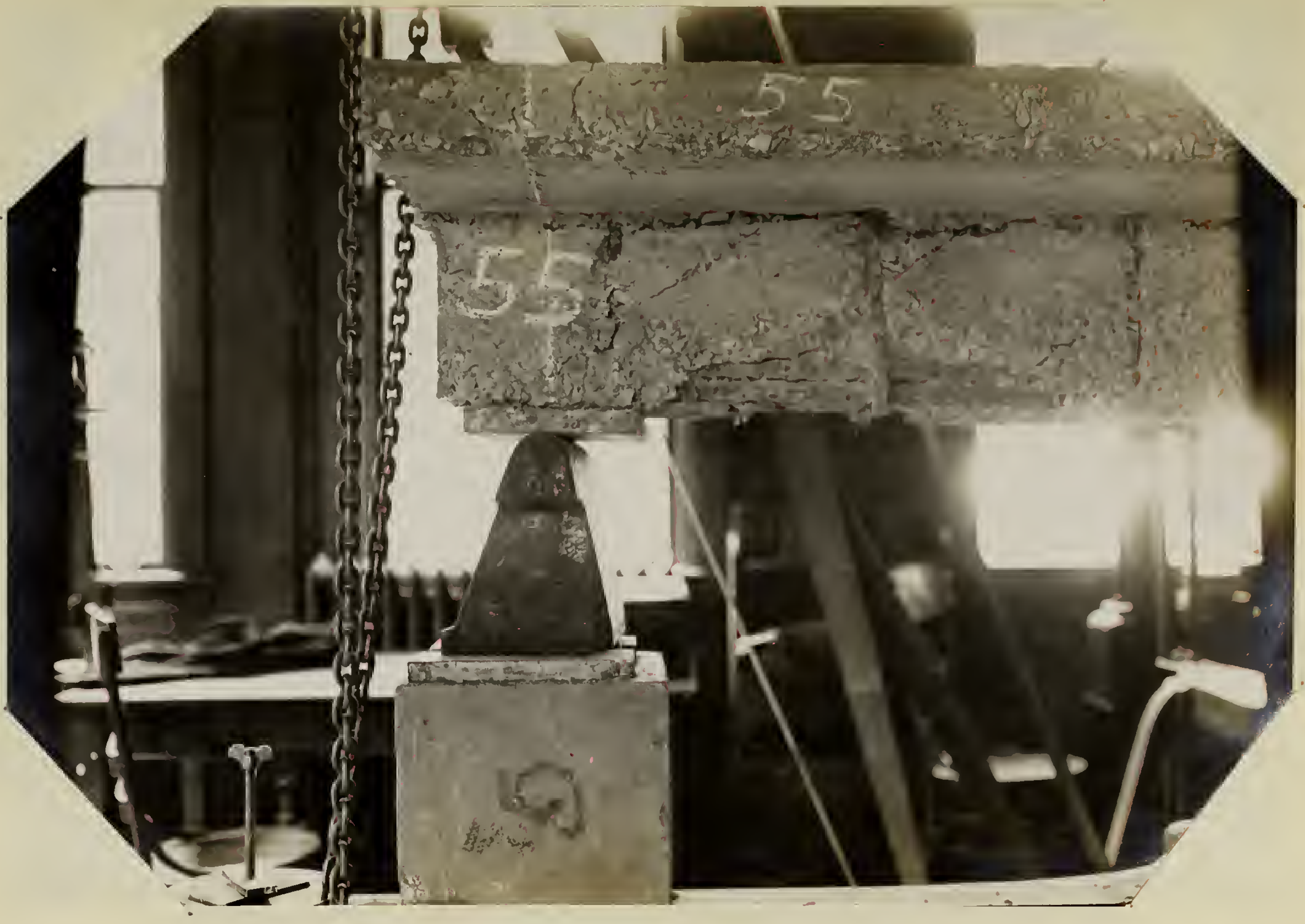

T-BEAM No.76
1.05% Reinforcement
Stirrups ½-in Mild Steel
Maximum Load 51200 lb.


Values of k
.20
.40
.60
.80
1.00
Applied Load Pounds
3000
6000
9000
12000
15000
18000
21000
24000
27000

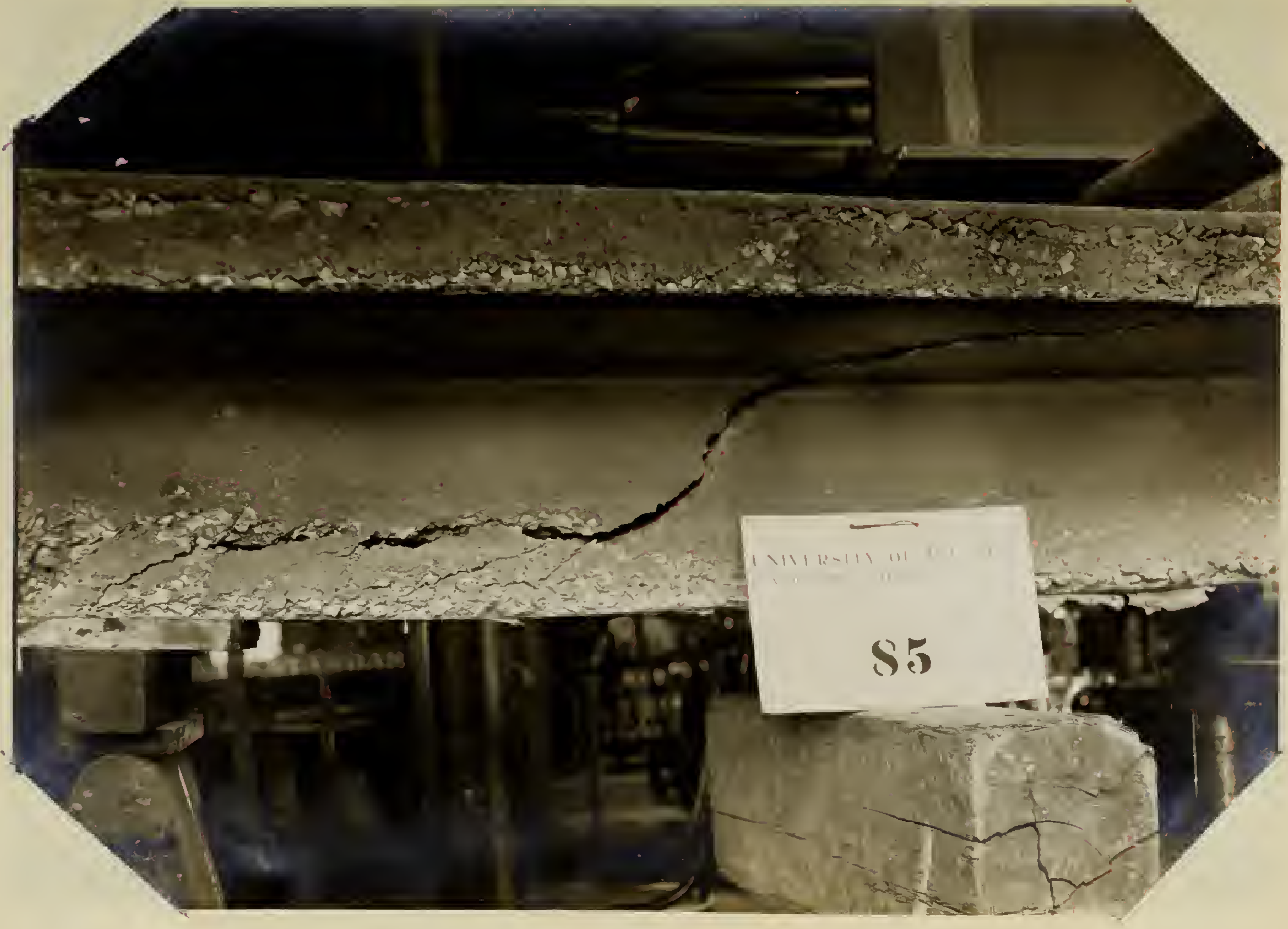

Applied Load Pounds
27000
24000
21000
18000
15000
12000
9000
6000
3000
00
Deformation Curves
Upper fiber
Steel
Deflection Curve
T-BEAM No. 86
1.05 % Reinforcement
No Stirrups
Maximum Load 17600 lb.
Deflection in inches
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Deformation per unit length.
.0002
.0004
.0006
.0008
0.010
.0012



T-Beam No. 50 Showing Failure by Diagonal Tension



T-Beam No. 55 Showing Failure by
Diagonal Tension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T-Beam No. 85 Showing Failure by Diagonal Tension

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